Modeling Long-Term Historic Lake Stage Fluctuations for Lake MFL Assessments

Second of Three Presentations

Presented to NTB II (LTPRG)

February 13, 2007

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Hydrologic Evaluation Section
SWFWMD

Today's Discussion

- Review of Last Presentation
- Introduction to LOC Regression to Produce a 60 Year Historic Record
- Present First LOC Model Lake Miona Based on Sharpes Ferry Well (Water Level Model)
- Present Lake Miona Model Based on Ocala Rainfall
  - Explanation of Rainfall Decay Series
- Comparison of the two Models
- Present Model of Sharpes Ferry Using Ocala Rain Gauge

Last Time We Discussed:

- MFL Terminology
  - Historic
  - Current
  - Structural Alteration
  - Long-Term
  - P10
  - P50
  - P90
  - Minimum Lake Level
  - High Minimum Lake Level
  - High Guidance Level

- Analysis of Long-Term

- Lake Stage Fluctuation Statistics Used to Set Lake Minimum Levels
  - Perfect World Example

- Tying Climate and Minimum Lake Levels Together

Structural Alteration:

- Change to the conveyance system of the lake that changes the lake stage fluctuation in a measurable manner.

- Usually, but not always, it involves a change to the outlet of the lake.

- Can include downstream alterations that result in tail water effects.

- Can include up stream changes that either increase or decrease flow to the lake.

- We recognize sinkholes during compliance evaluation, but usually don’t set the level based on them.

Historic

1. Period with no measurable groundwater or withdrawal impacts

2. Structural conditions same as now

4. No Augmentation

Current

1. ~~No~~ Groundwater or withdrawal impacts

2. Structural conditions same as now

3. No Augmentation

Minimum Lake Levels are Long-Term Percentiles

- Minimum Lake level is the Historic P50 minus some offset.

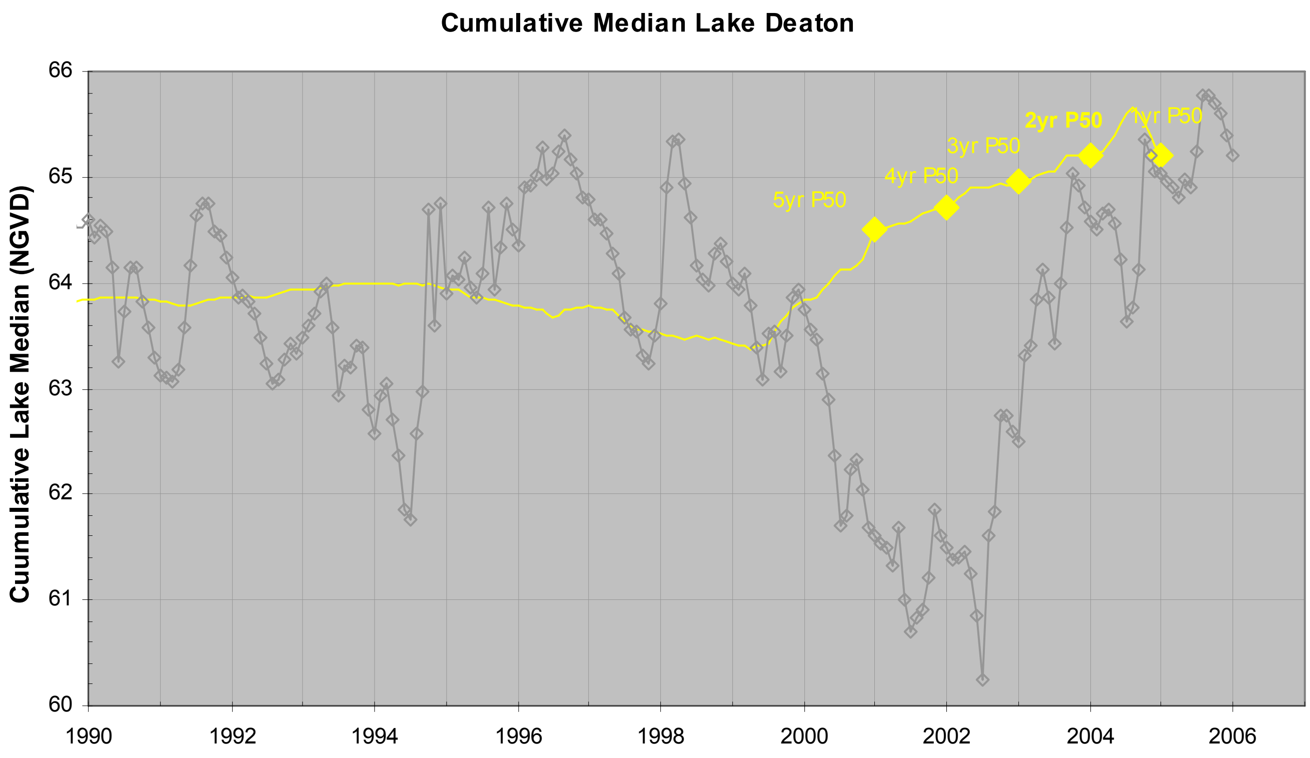
  MLL represents a new P50 value

- High Minimum Lake Level is the Historic P10 minus some offset.

  HMLL represents a new P10 value

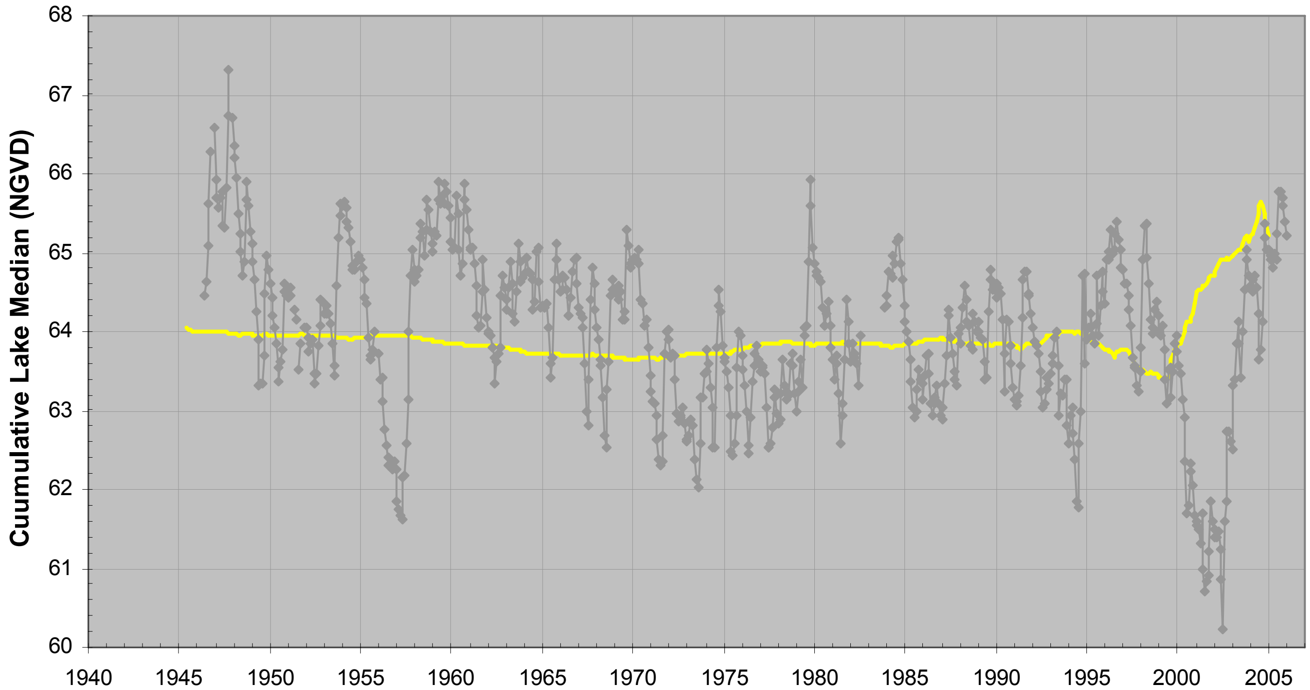
- High Guidance Level is the Historic P10 (i.e. no offset)

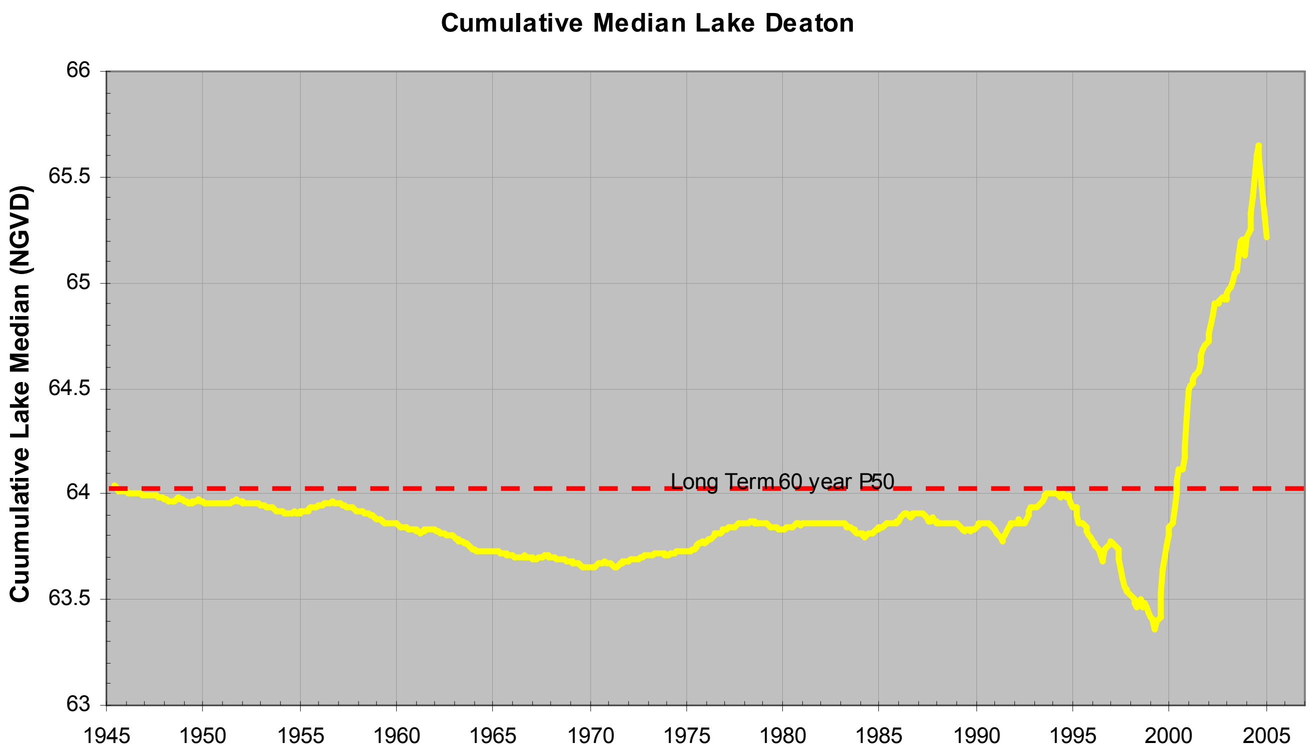
  HGL = Historic P10



Cumulative Median Lake Deaton
Cuumulative Lake Median (NGVD)
66
65
64
63
62
61
60
1990
1992
1994
1996
1998
2000
2002
2004
2006
5yr P50
4yr P50
3yr P50
2yr P50
1yr P50

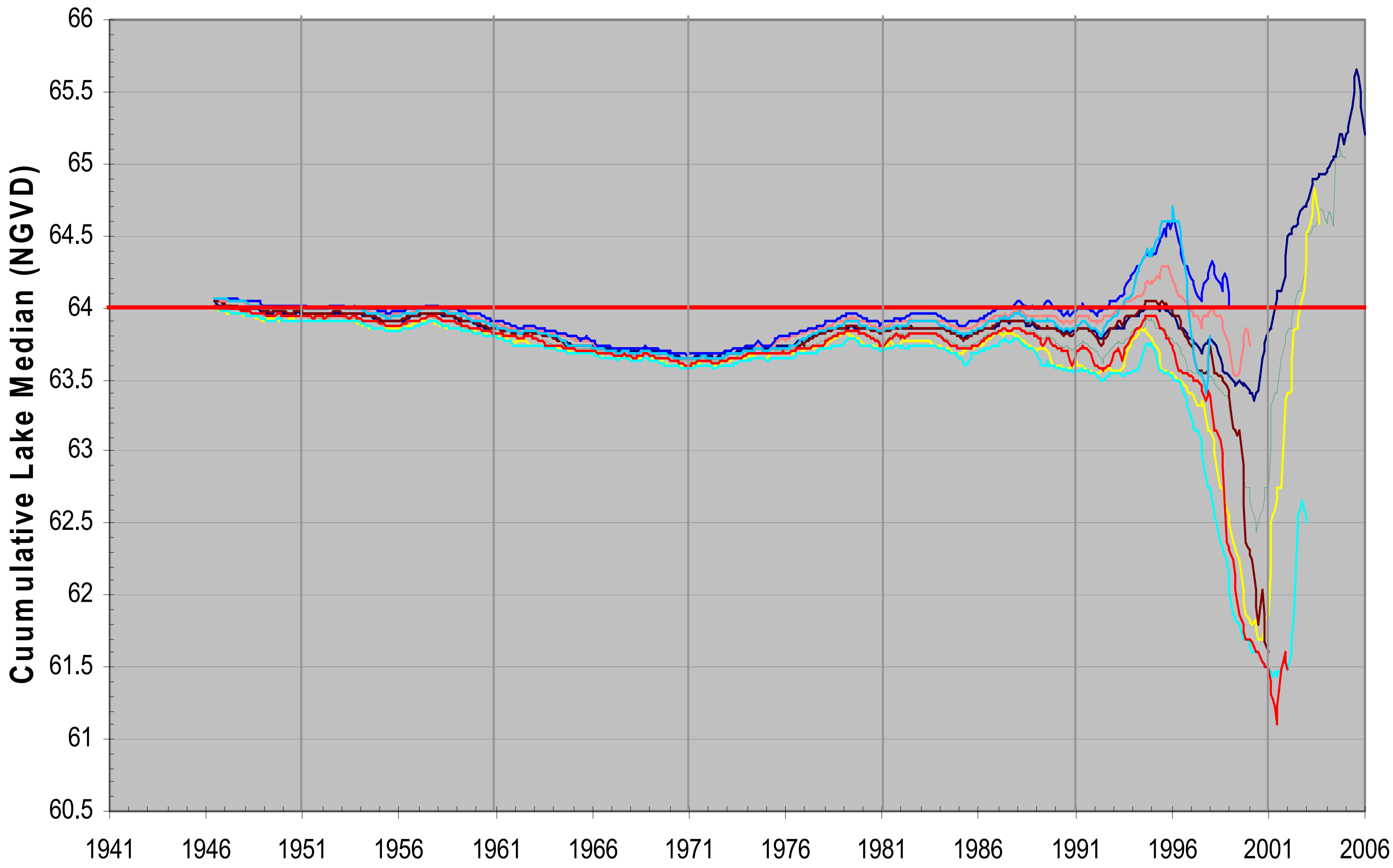
Cumulative Median Lake Deaton

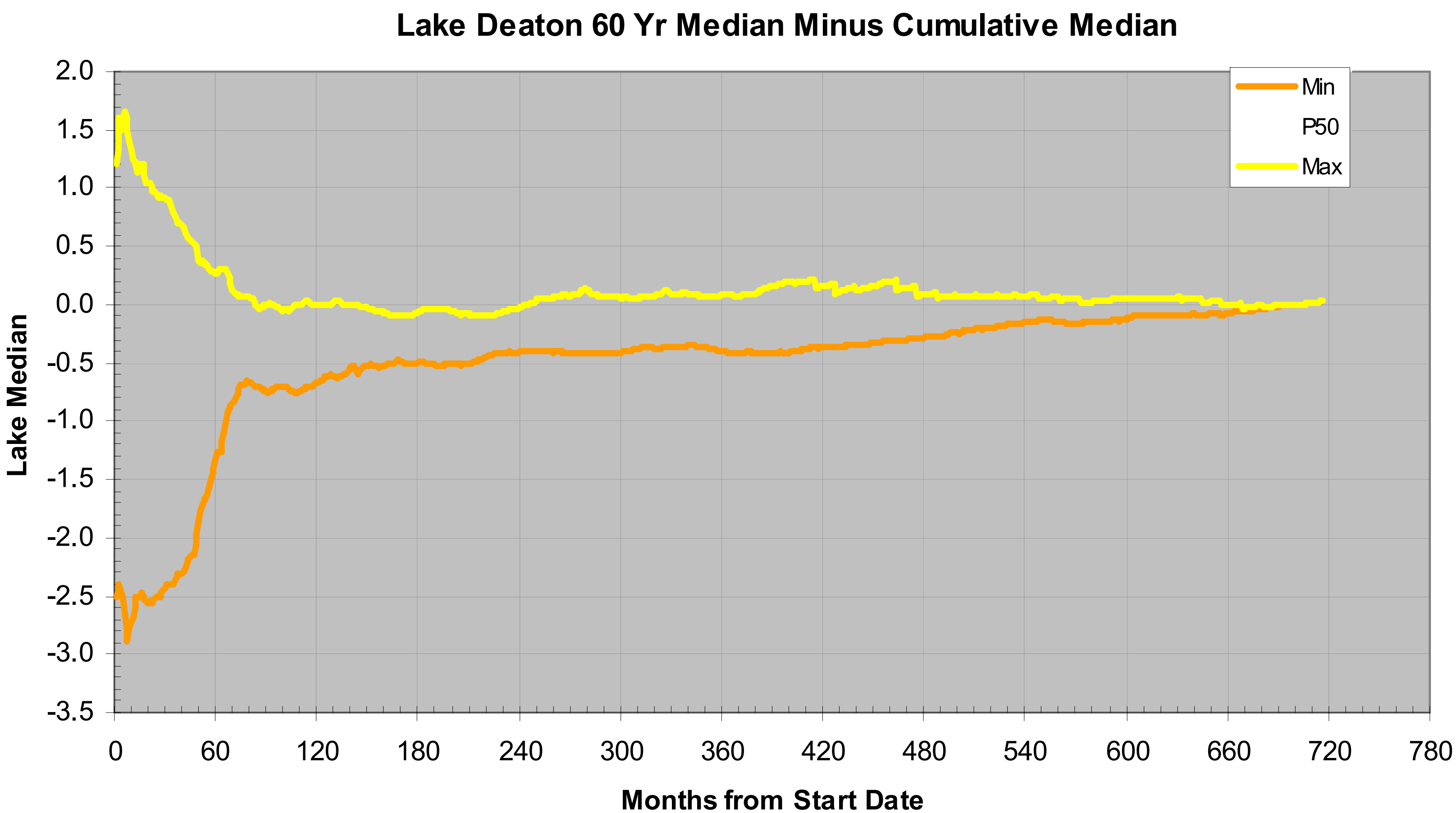




Cumulative Median Lake Deaton
Cuumulative Lake Median (NGVD)
66
65.5
65
64.5
64
63.5
63
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
Long Term 60 year P50

Cumulative Median Lake Deaton




Lake Deaton 60 Yr Median Minus Cumulative Median
Min
P50
Max
Lake Median
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
0
60
120
180
240
300
360
420
480
540
600
660
720
780
Months from Start Date

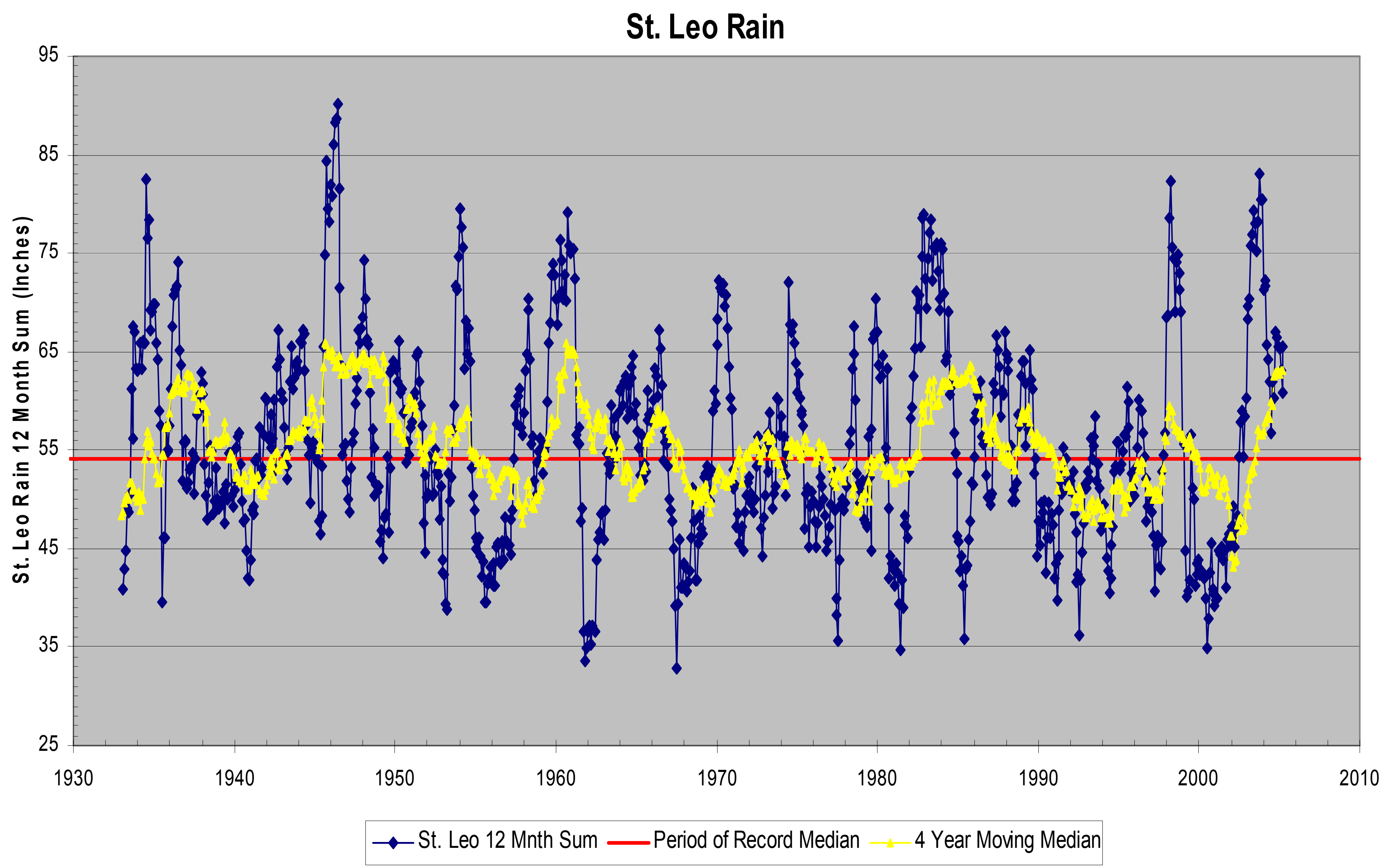
<u>Long-Term is at Least 60 + Years</u>

(Actually there are cycles in cycles, that will keep producing new values but we are setting a limit at 60 to 100 years)

<u>Fact:</u>

1. Percentiles calculated with shorter windows of time will cycle above and below the longer term percentile.

2. The shorter the window of time the larger the variation around the long-term.

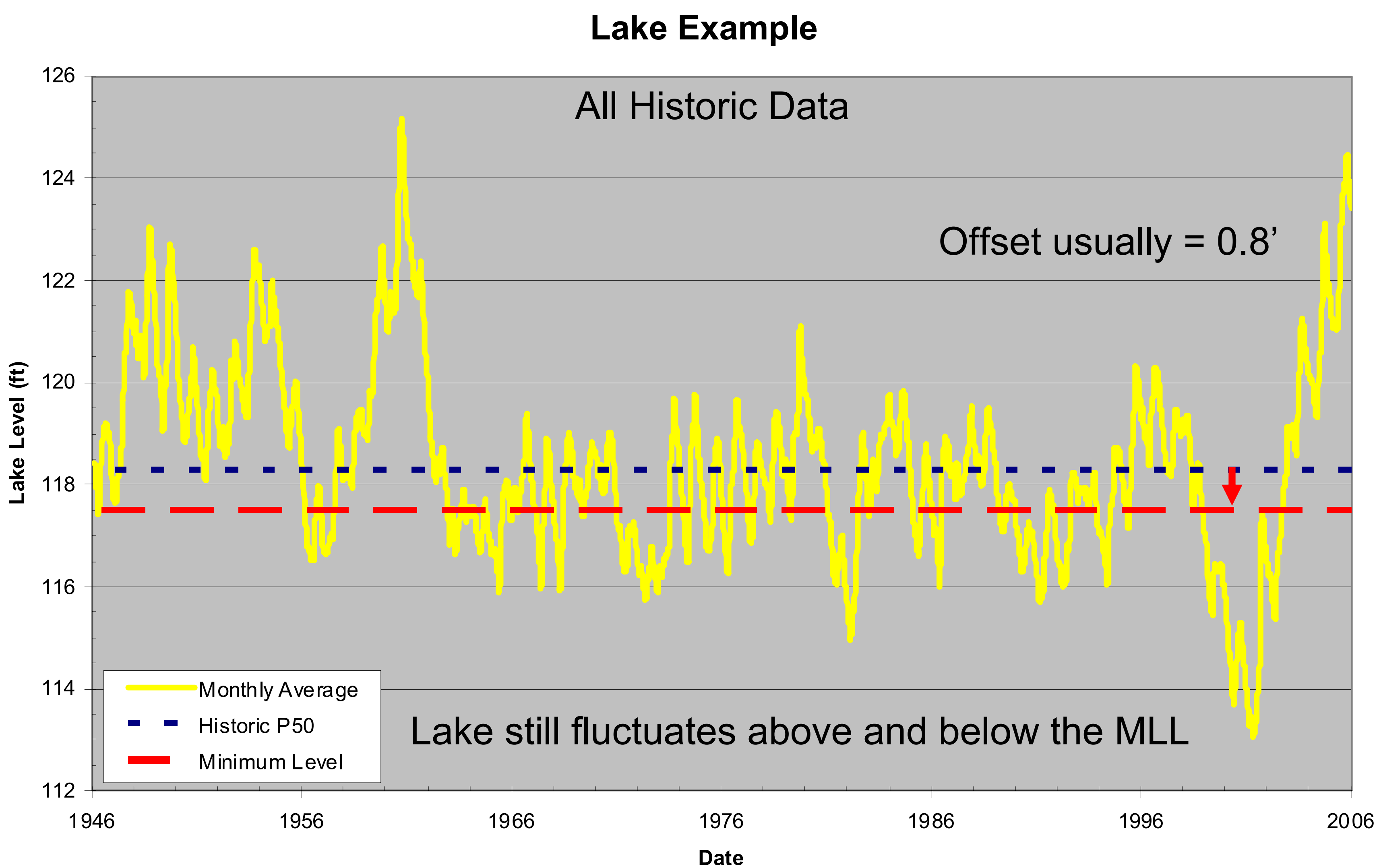


D.L.E. August 21, 2006

Calculating Lake Stage Fluctuation Statistics Used to Set Lake Minimum Levels

In a perfect world you have long-term historic data and it's very easy!

Calculate the Historic P50 using the data and apply the appropriate offset.



Lake Example
All Historic Data
Offset usually = 0.8'
Lake still fluctuates above and below the MLL
Lake Level (ft)
126
124
122
120
118
116
114
112
1946
1956
1966
1976
1986
1996
2006
Date
Monthly Average
Historic P50
Minimum Level

We never have a perfect world situation.

- **Need method to calculate Long-Term Historic P50.**

- **Need a method to estimate what the natural stage of the lake should be at any moment based on preceding climatic conditions**

Typical lake has less than 20 years and very frequently has no historic data.

How are we handling this?

1. Old Way - Reference Lake Water Regime concept

2. New Way – Climate Based Models

Goal: Estimate Lake Stage Given Climatic Conditions

Brief Introduction to Line of Organic Correlation (regression)

- Fully discussed in Helsel and Hirsch (1992)

  Studies in Environmental Science 49

  Statistical Methods in Water Resources

  USGS,Water Resources Division

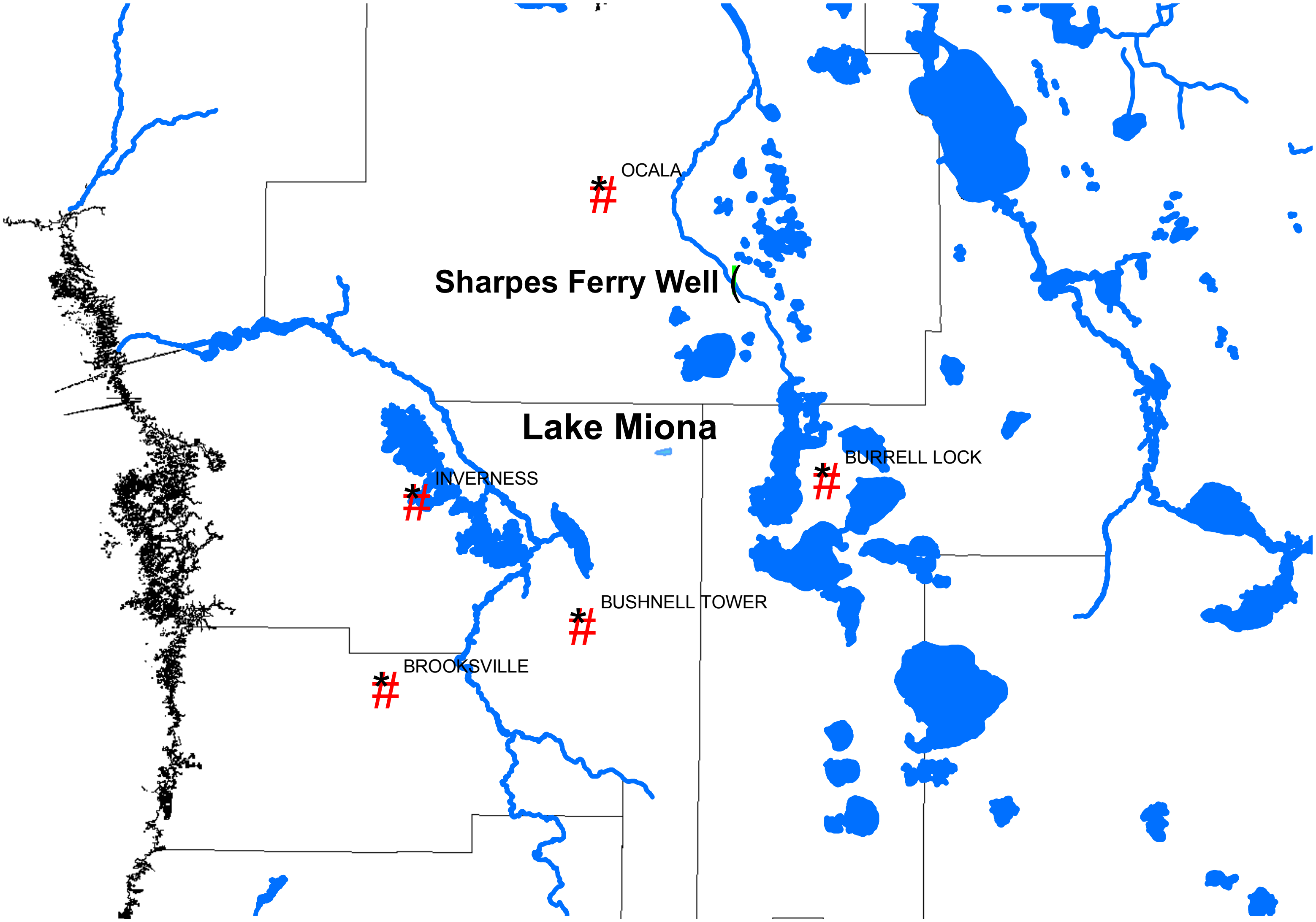
- Minimizes Error in Both x and y direction

- Slightly different form of regression

- Good to fill in missing data using overlapping records two stations

First Application of LOC - Lake Miona Model Based on Sharpes Ferry Well

(Hancock 2007)

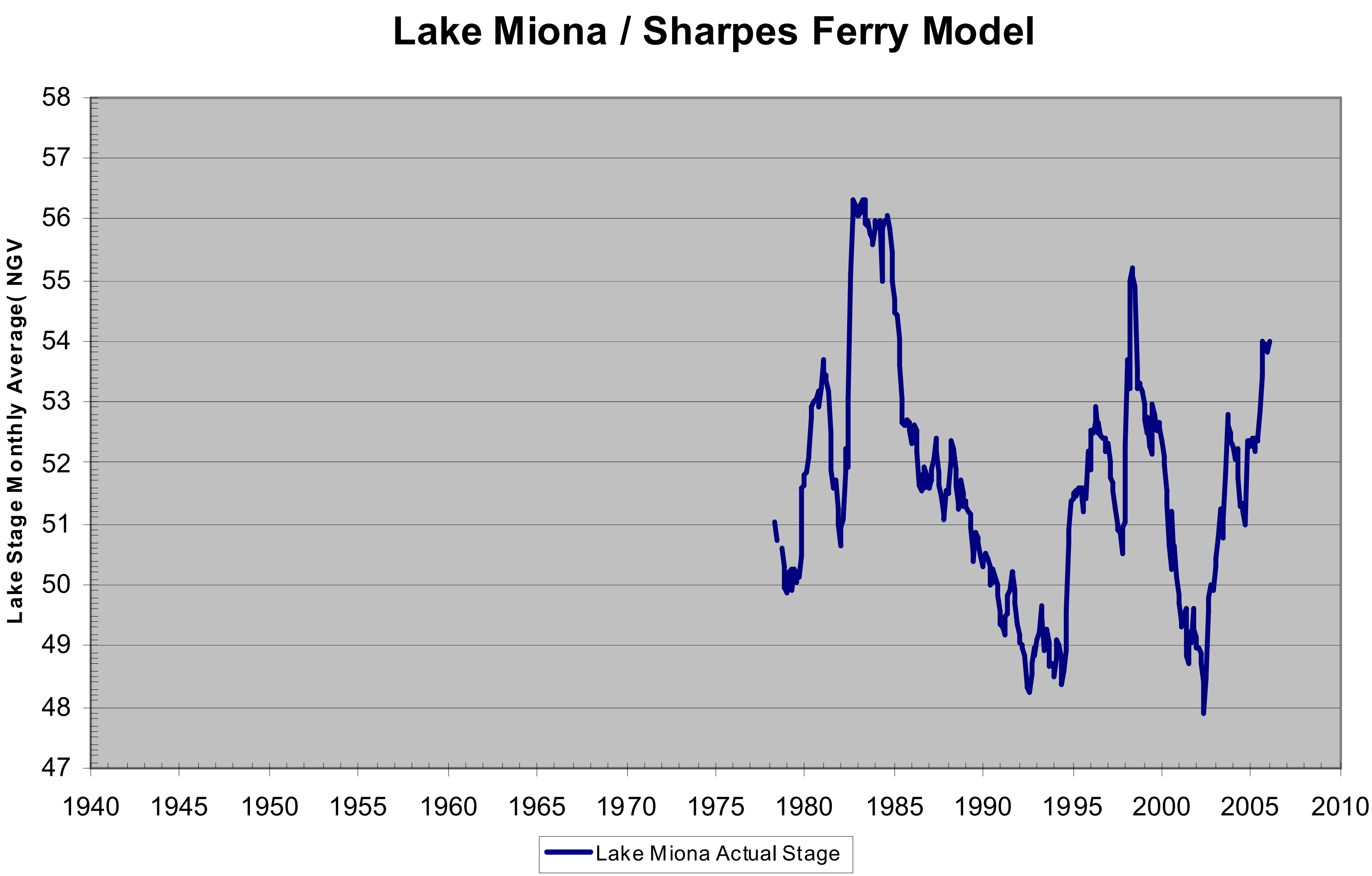

OCALA
Sharpes Ferry Well
Lake Miona
BURRELL LOCK
INVERNESS
BUSHNELL TOWER
BROOKSVILLE

Sharpes Ferry Background

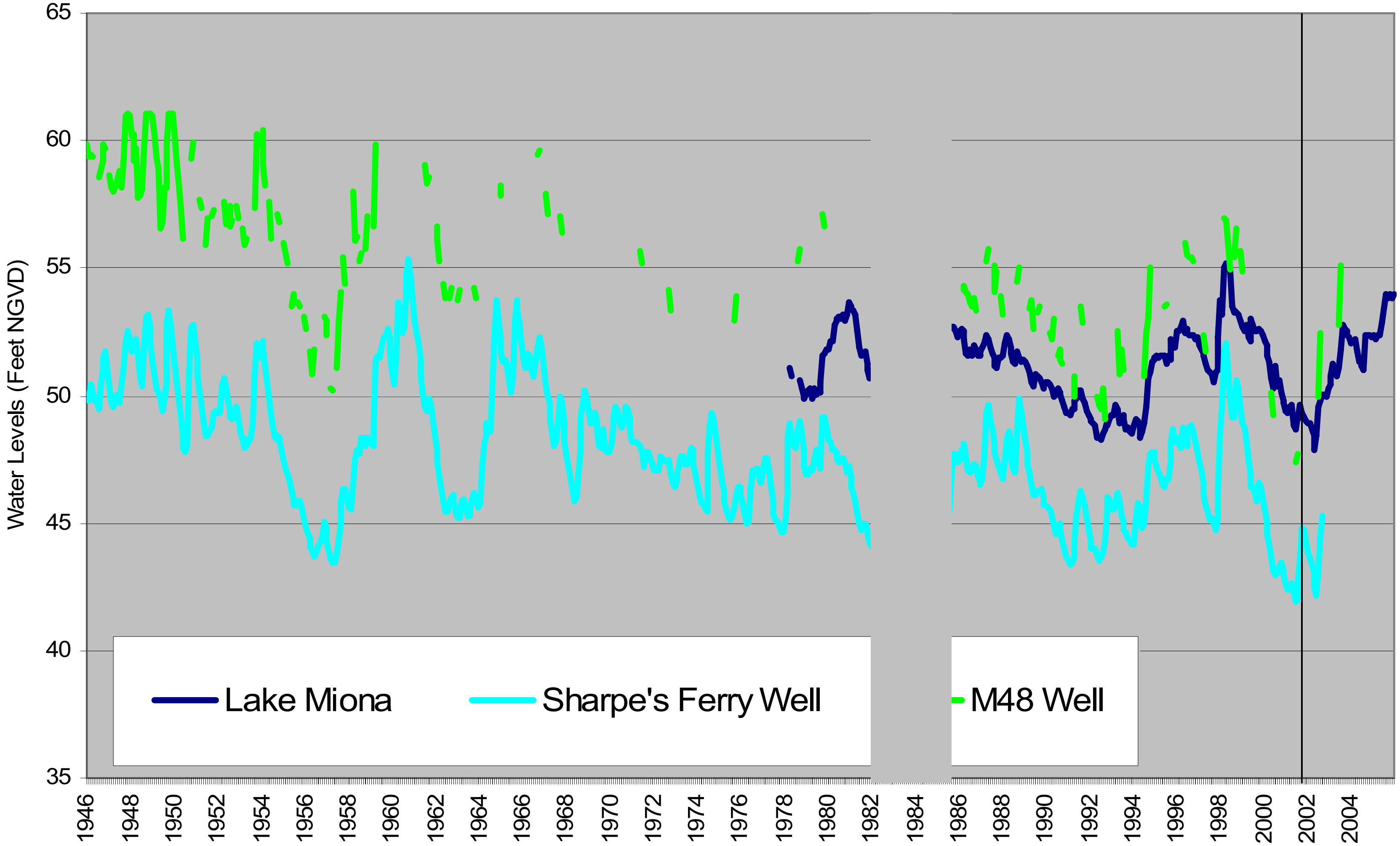
- Data Collected by USGS since 1947
- Located Adjacent to the Ocklawaha River Near Sharpes Ferry
- Floridan Well
- Abandoned in 2002 and not replaced
- Some debate over level of impact by water use, but area has been and still is a low use area.
- Change in Water Levels on Harris Chain of Lakes due to Moss Bluff Structure and thus changes to the Ocklawaha River are reported by Tibbals 2004.
- SWFWMD Considers it one of the few hydrologic records with very minimal impacts. Our best Long-term data set for testing models.

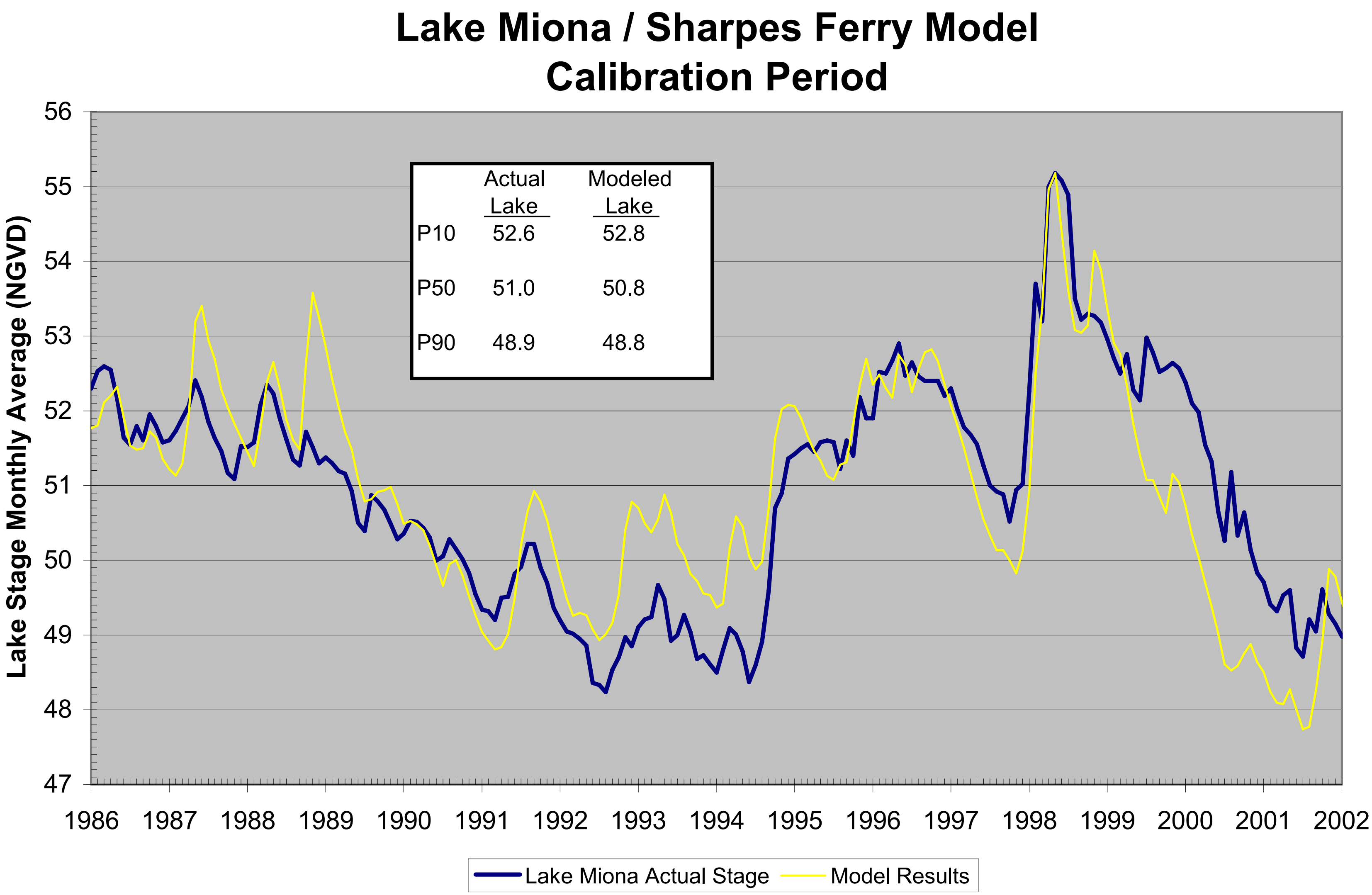
Lake Miona Background

- Lake Stage Data Available from April 1978 to Present
- Past Peat Mining In Basin with Possible Augmentation to Miona from Peat Dewatering Activities (1982-1986)
- Area of Rapid Growth Since 2000 with substantial recent water use increases
- Closed Basin no Structural Alterations
- Good Biological Indicators are Absent
- Analysis of water use impacts suggest little to none up to 2000-2002

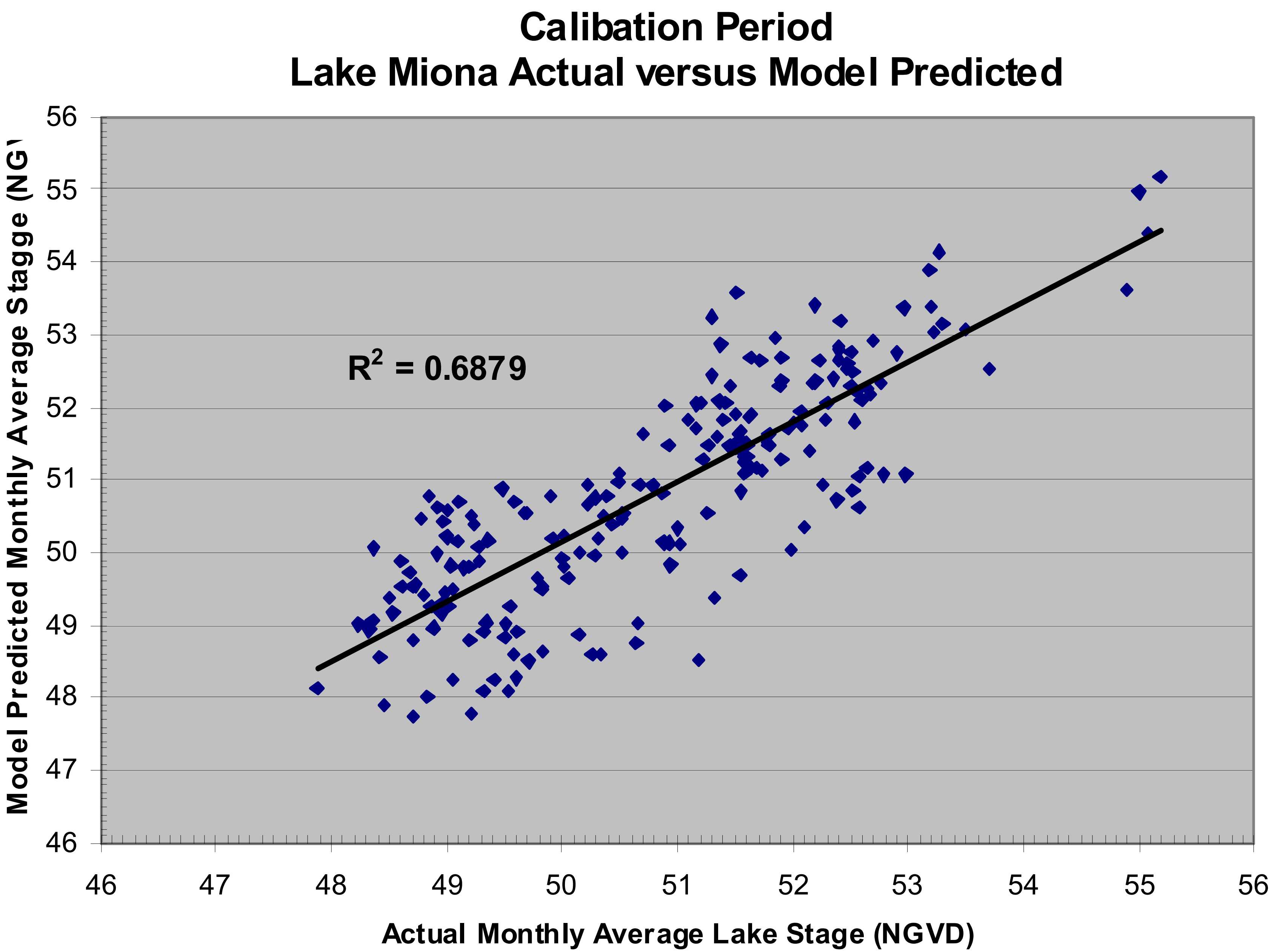

Lake Miona / Sharpes Ferry Model
Lake Stage Monthly Average(NGV
58
57
56
55
54
53
52
51
50
49
48
47
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
Lake Miona Actual Stage

Lake Miona / Sharpes Ferry Water Level Based Model

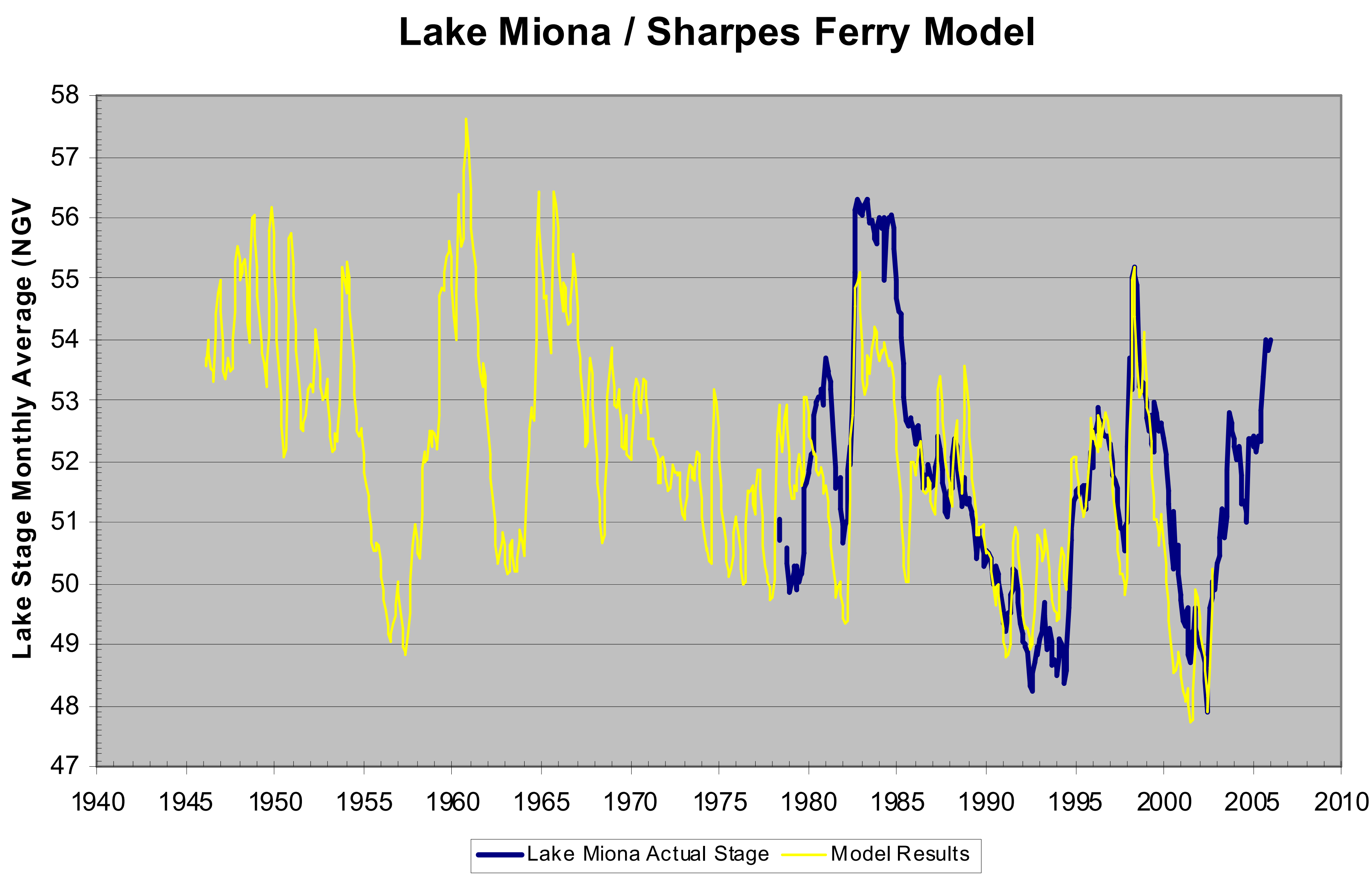




Lake Miona / Sharpes Ferry Model
Calibration Period
Lake Stage Monthly Average (NGVD)
56
55
54
53
52
51
50
49
48
47
Actual Lake
Modeled Lake
P10 52.6 52.8
P50 51.0 50.8
P90 48.9 48.8
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Lake Miona Actual Stage
Model Results



Calibation Period
Lake Miona Actual versus Model Predicted
R^2 = 0.6879
Model Predicted Monthly Average Stage (NG
Actual Monthly Average Lake Stage (NGVD)
46
47
48
49
50
51
52
53
54
55
56



Lake Miona / Sharpes Ferry Model
Lake Stage Monthly Average (NGV
58
57
56
55
54
53
52
51
50
49
48
47
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
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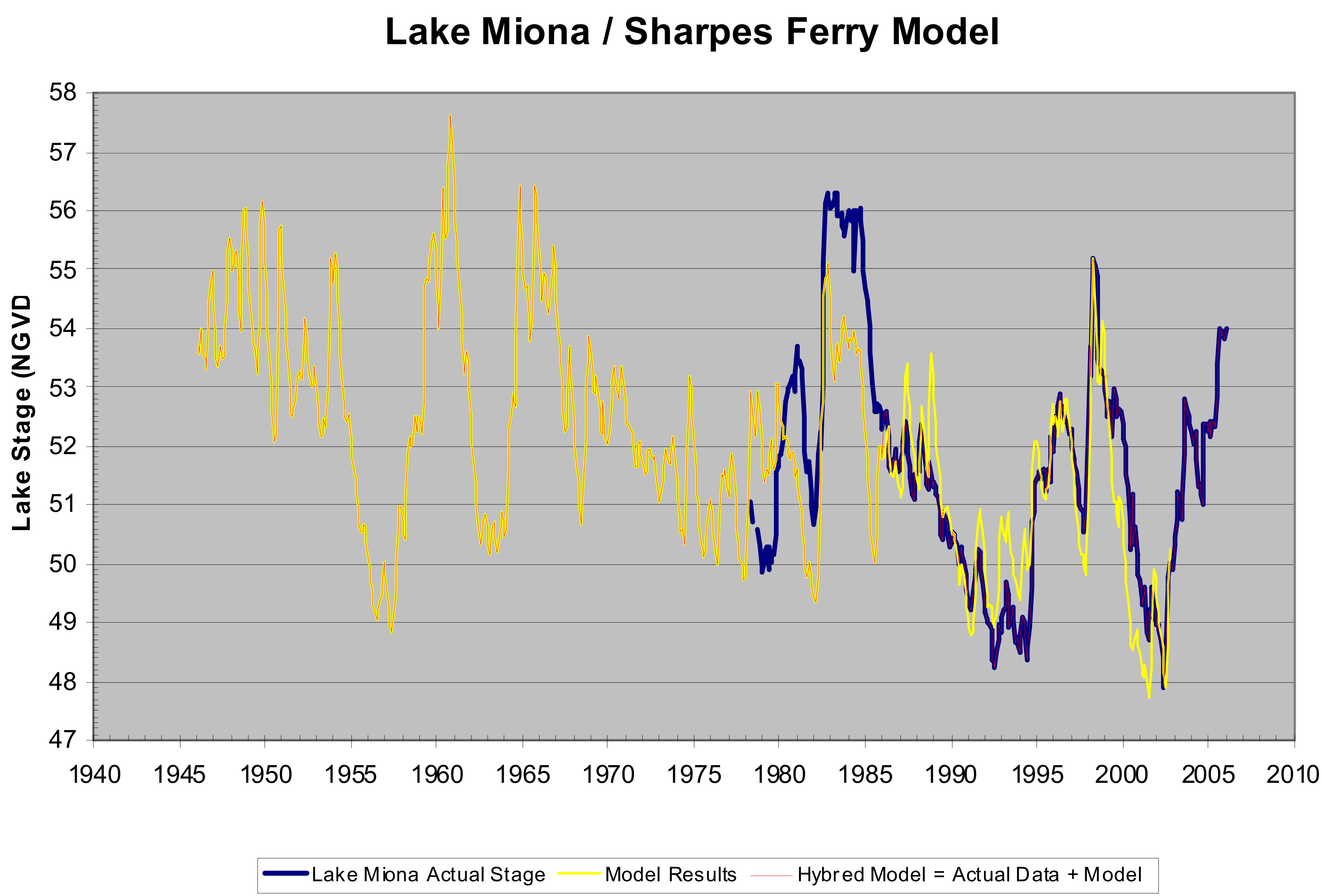
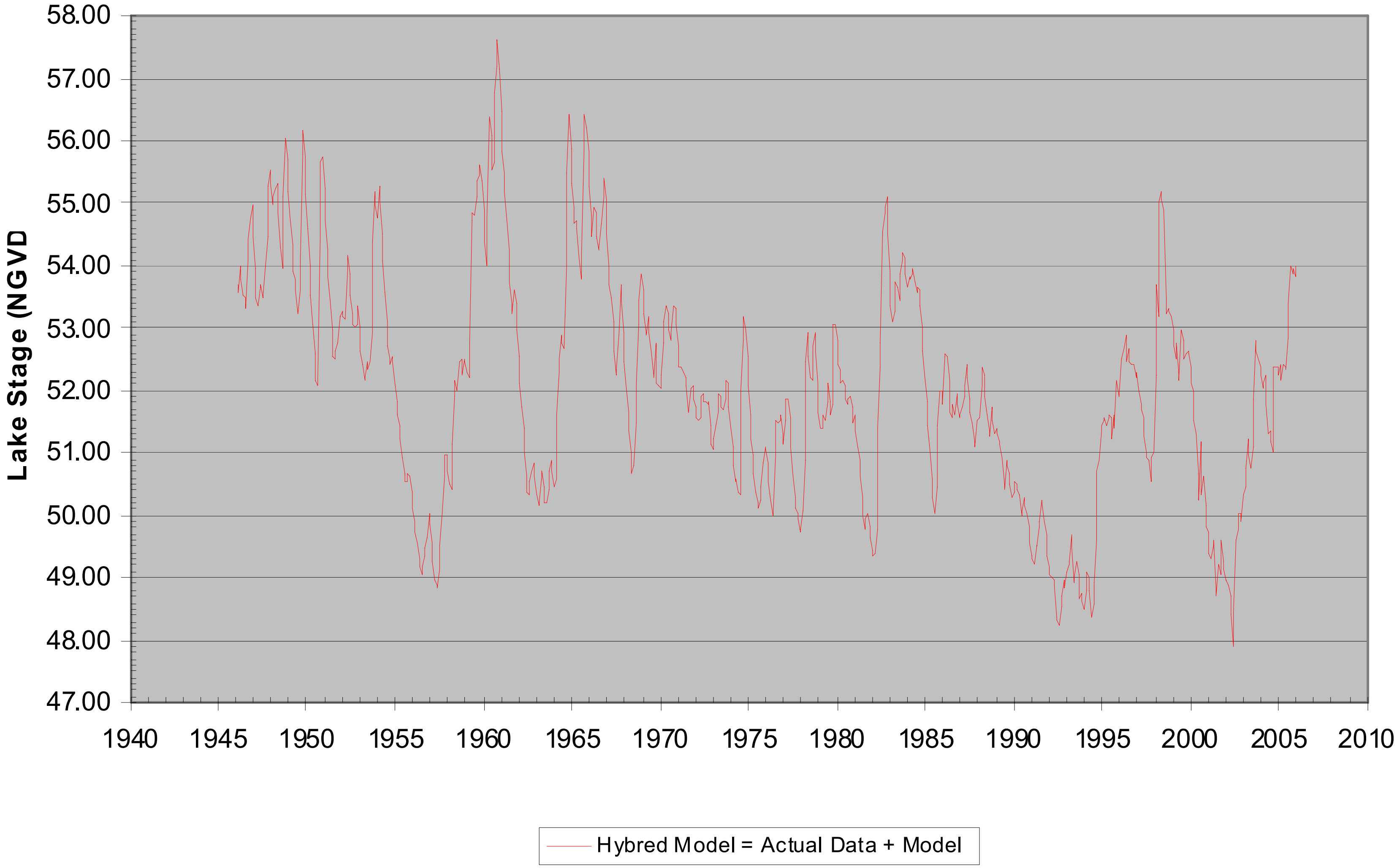
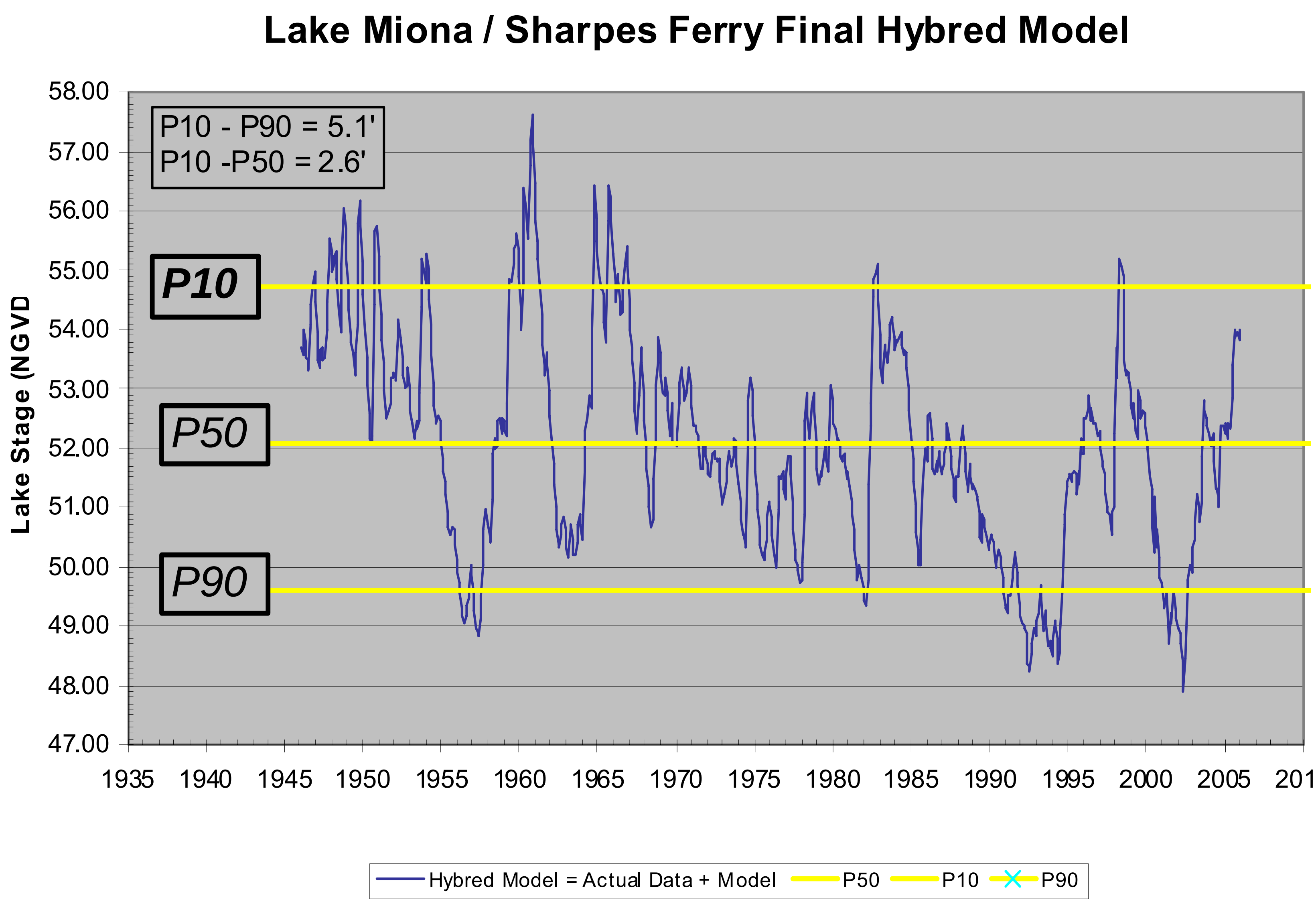
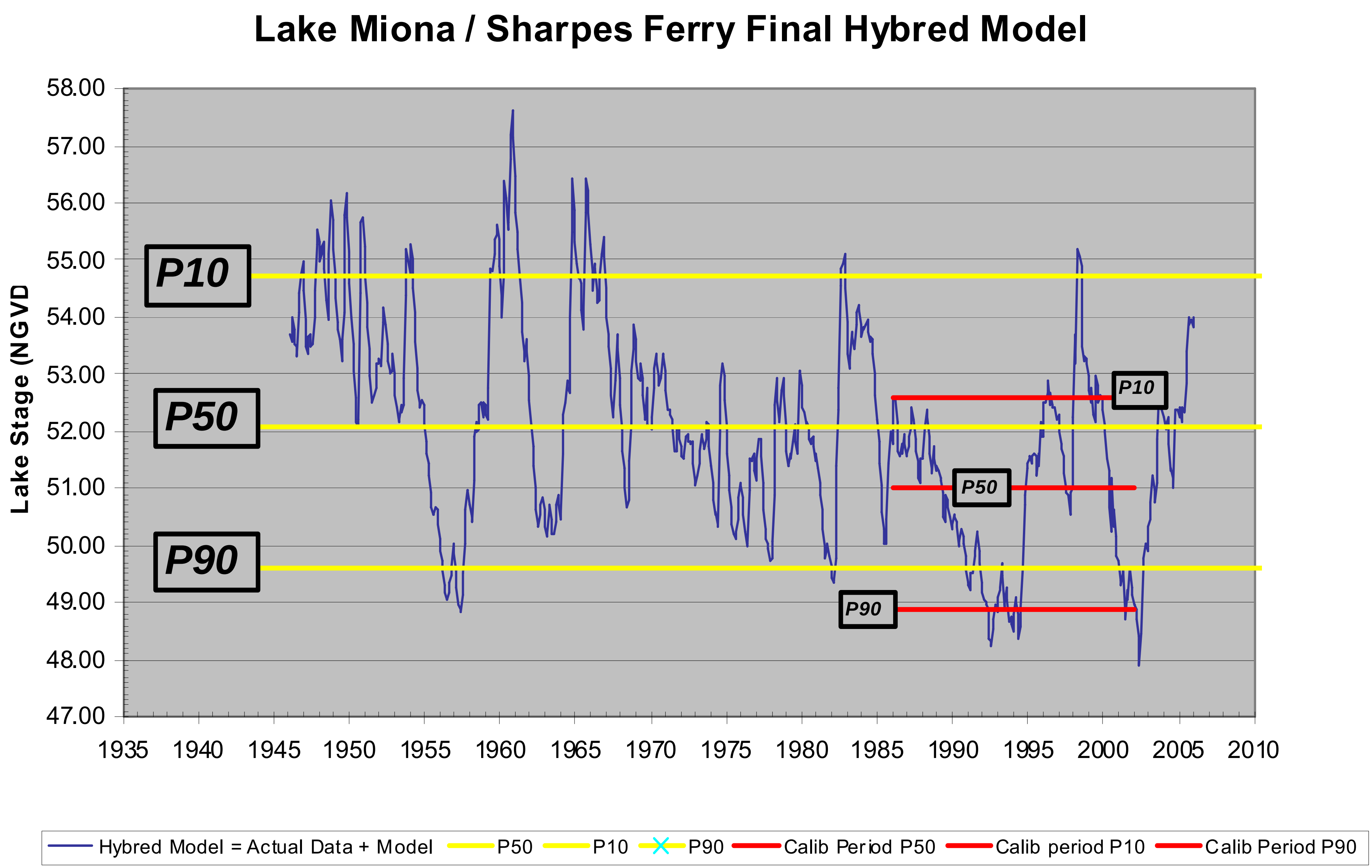
1995
2000
2005
2010
Lake Miona Actual Stage
Model Results


Lake Miona / Sharpes Ferry Model
Lake Stage (NGVD
58
57
56
55
54
53
52
51
50
49
48
47
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
Lake Miona Actual Stage
Model Results
Hybred Model = Actual Data + Model

Lake Miona / Sharpes Ferry Final Hybred Model




Lake Miona / Sharpes Ferry Final Hybred Model
P10 - P90 = 5.1'
P10 -P50 = 2.6'
P10
P50
P90
Lake Stage (NGVD
58.00
57.00
56.00
55.00
54.00
53.00
52.00
51.00
50.00
49.00
48.00
47.00
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
Hybred Model = Actual Data + Model
P50
P10
P90



Lake Miona / Sharpes Ferry Final Hybred Model
Lake Stage (NGVD
58.00
57.00
56.00
55.00
54.00
53.00
52.00
51.00
50.00
49.00
48.00
47.00
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
P10
P50
P90
P10
P50
P90
Hybred Model = Actual Data + Model
P50
P10
P90
Calib Period P50
Calib period P10
Calib Period P90

Lake Miona Model
Using the Ocala Rain Gauge
Instead of Sharpes Ferry
(Example of a Rainfall Model)

- Goal is a Climate Based Model to Predict Un-impacted Monthly Average Lake Level
- Eliminates Anthropogenic Changes in the Model
- Numerous Rain Gauges throughout the District to Use, Minimizing Location and Distance Issues
- Rain Gauges Still Exist, Haven't Been Abandoned

Lake Stage Models Based on Rainfall

- Rainfall is summed to relate to lake fluctuation
- Monthly sums are the starting data
- Method of summing is critical
  - Lake Stage is dependent on prior months of rainfall
  - Previous rainfall’s influence diminishes as time passes
  - Linear Inverse Weighted Sum or a Decay series addresses the fading memory issue

Rainfall Decay Series

- Lake stage is a result of current rain and past rain
- Lakes have a fading memory of past rainfall
- This months rain is more influential than rain that occurred 3 months ago, and the rain three months ago is more influential than 6 months ago. and so on…….

Rainfall Decay Series

- To capture this concept each month of rainfall is weighted
- With the highest weight assigned to the current month and decreasing weights are assigned to each month back in time
- A simple linear decreasing weighting system is used

Example - Calculation of 12 Month Rainfall Decay Series Sum

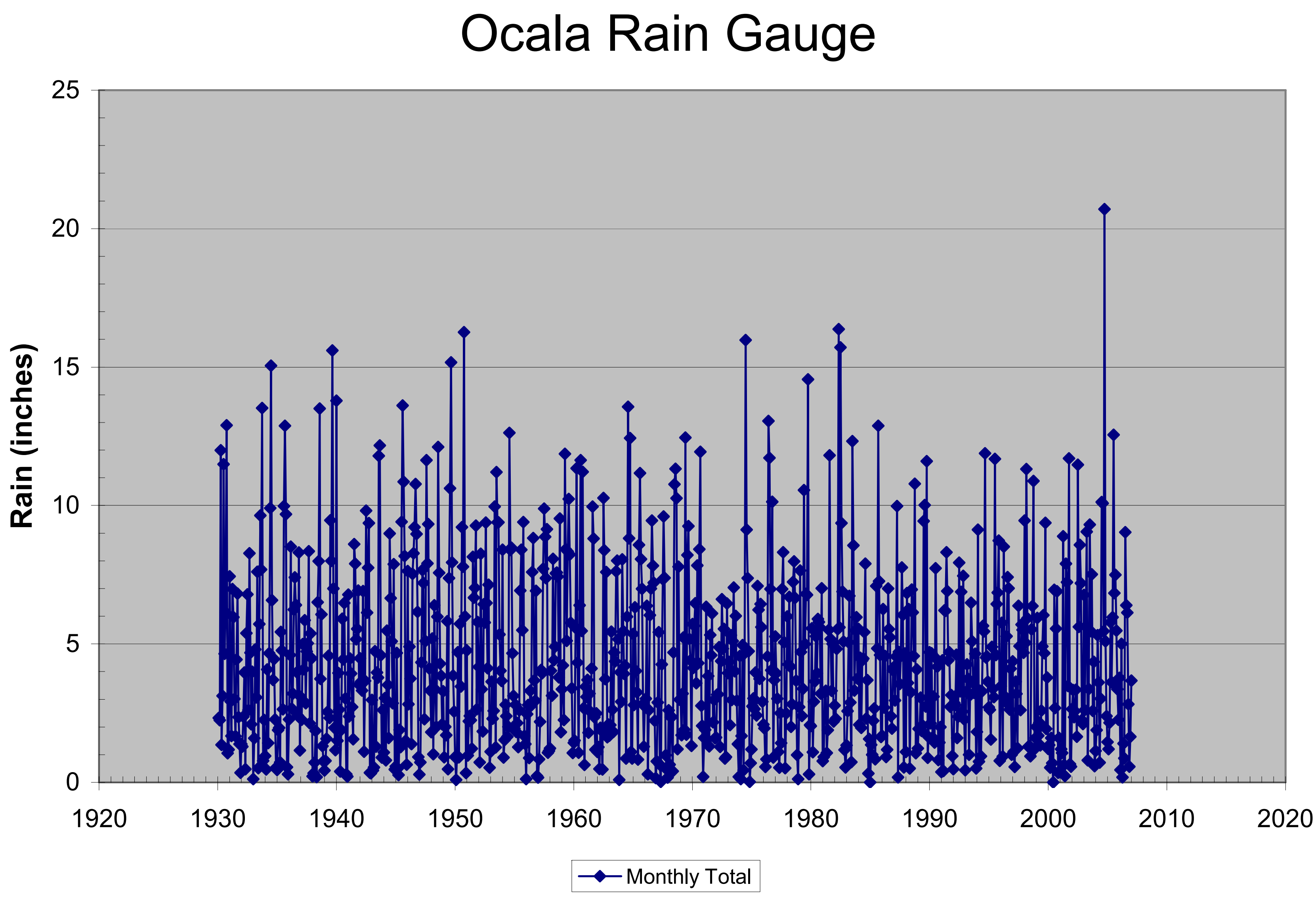
Rain Monthly Total (inches)	Sum of Rain Decay Series (inches)
R_1	$D_1 = R_1 (12/12) + R_2 (11/12) \ldots + R_{12} (1/12)$
R_2	$D_2 = R_2 (12/12) + R_3 (11/12) \ldots + R_{13} (1/12)$
R_3	$D_3 = R_3 (12/12) + R_4 (11/12) \ldots + R_{14} (1/12)$
.	.
.	.
.	.
R_x	$D_x = R_x (12/12) + R_{(x+1)} (11/12) \ldots + R_{(x+11)} (1/12)$
$R_{(x+1)}$	
$R_{(x+2)}$	
.	
.	
.	
$R_{(x+11)}$	

Decay Series Expression

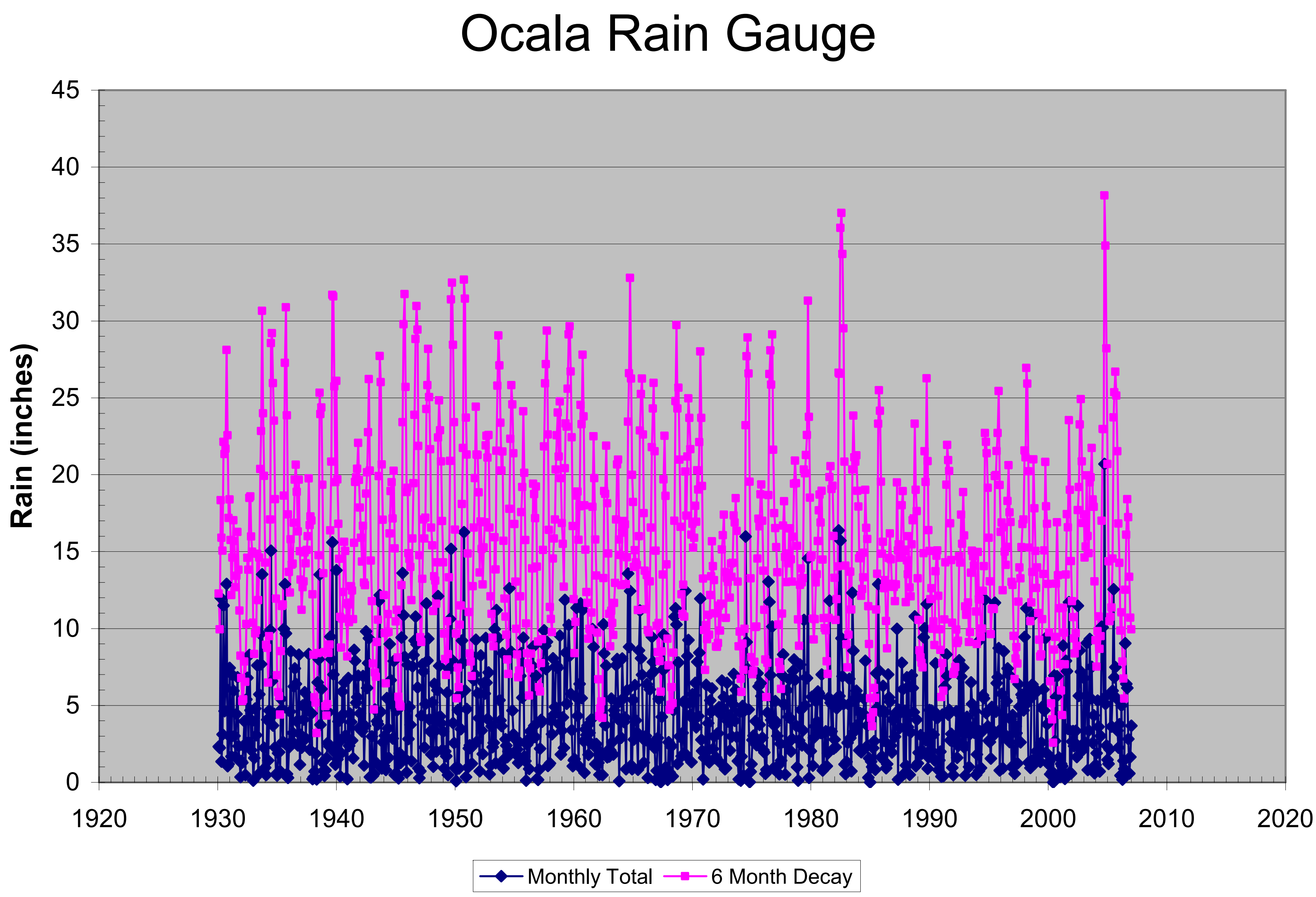
The general form of the decay series expression is:

$$Dx = Rx\ (L/L) + R(x+1)\ ((L-1)/L) + \ldots + R(x+L)\ ((L-L)/L)$$

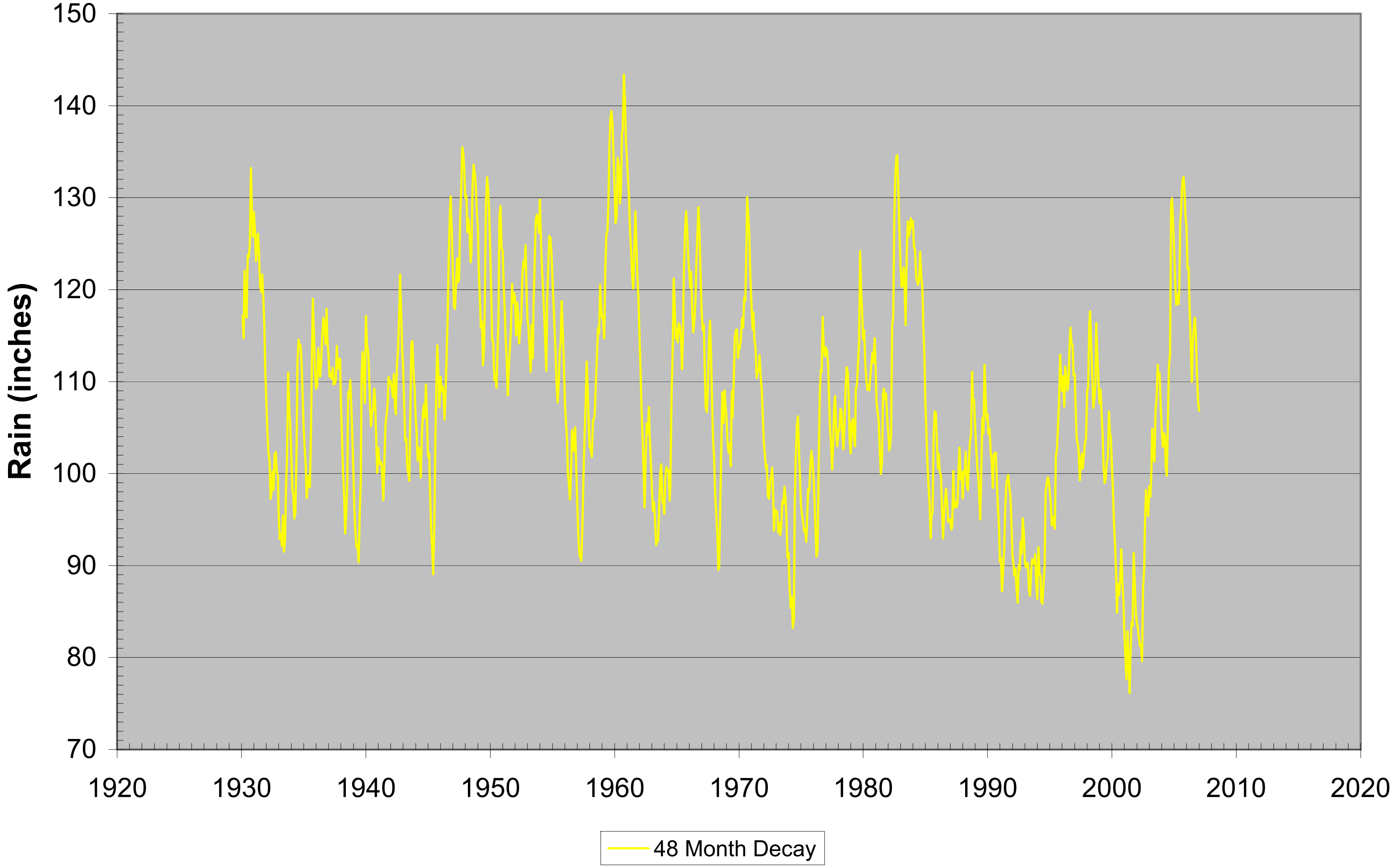
Where: L = number of months in the decay period
Dx is the sum of the rain decay series



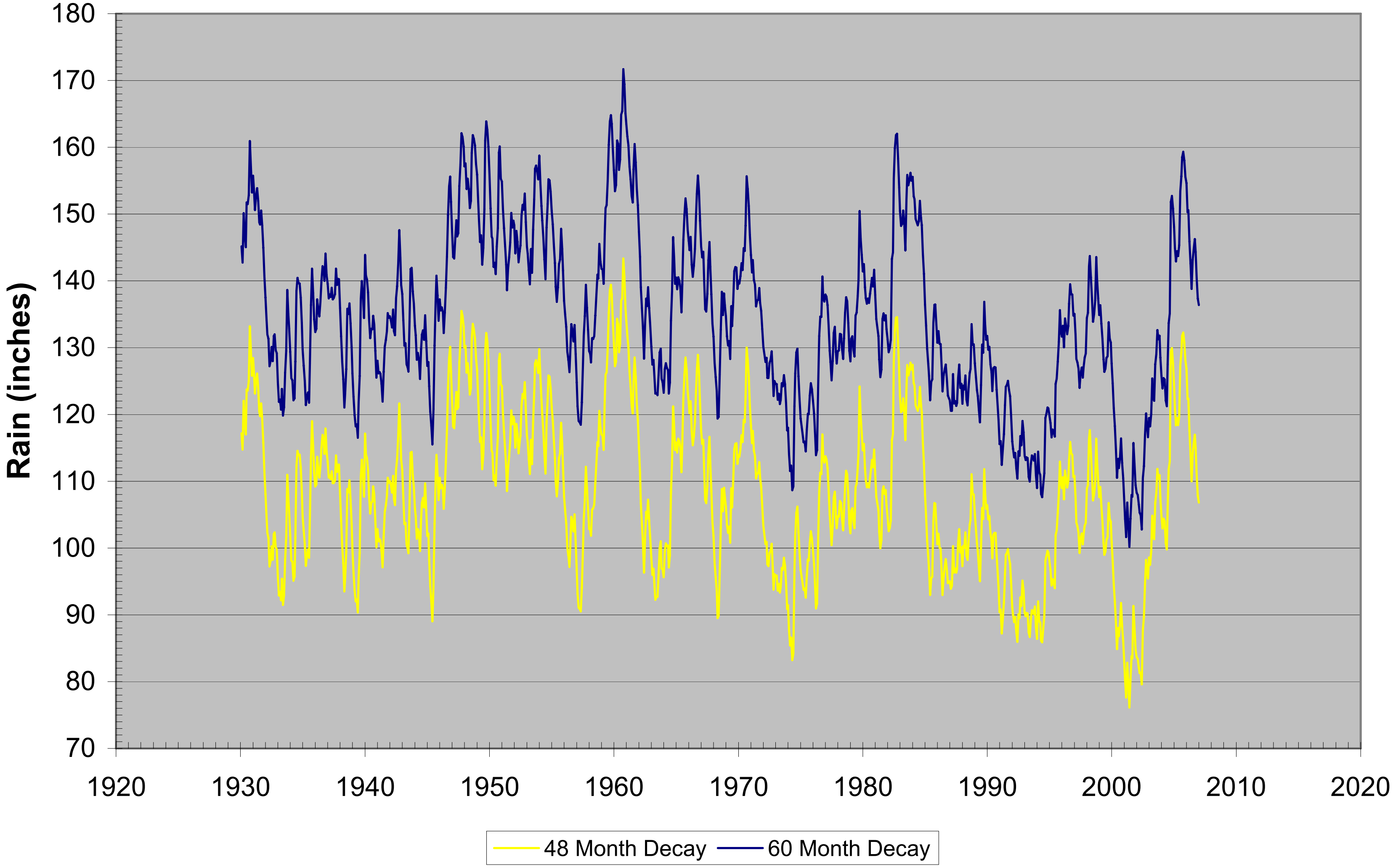
Ocala Rain Gauge
Rain (inches)
0
5
10
15
20
25
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Monthly Total

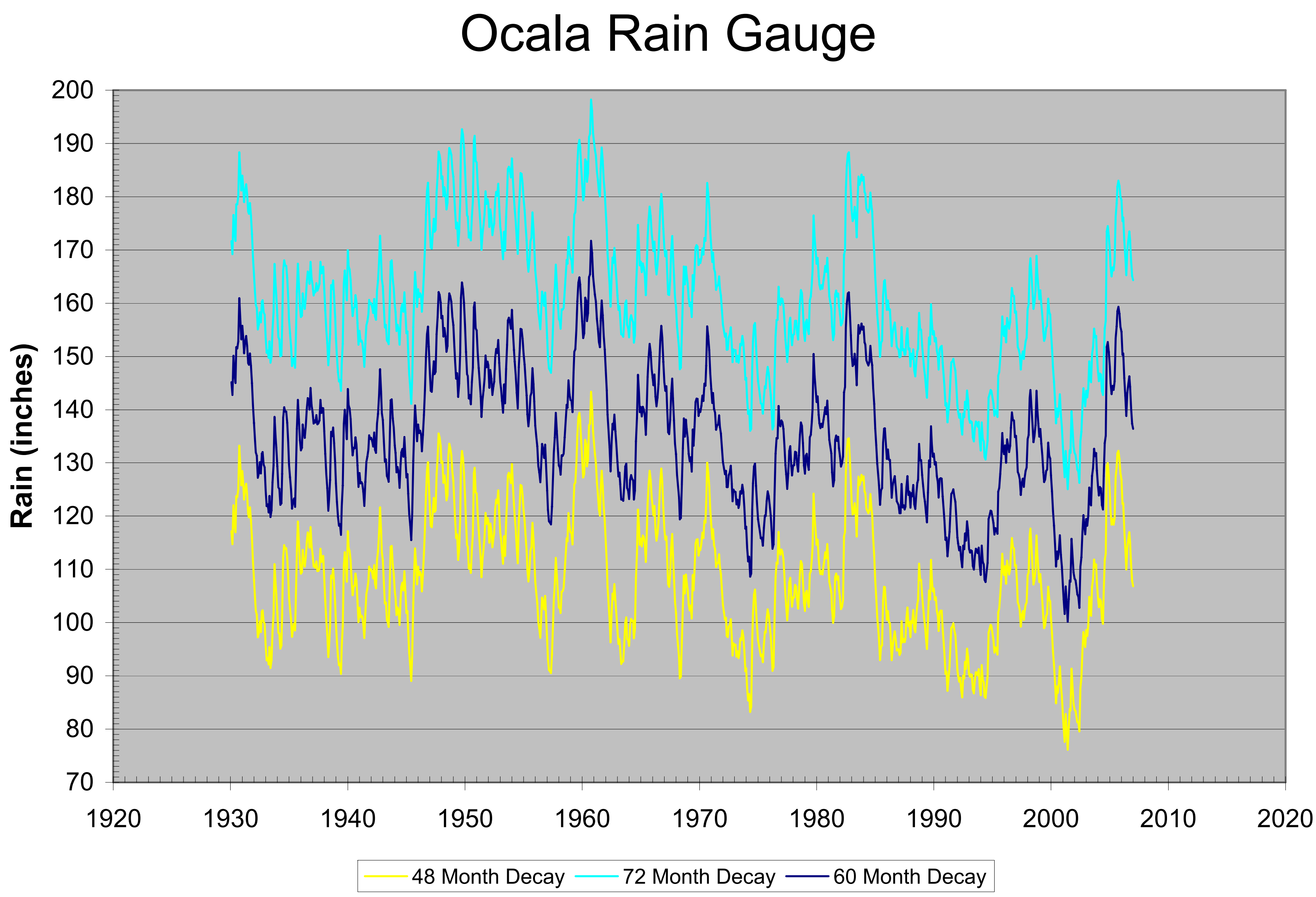

Ocala Rain Gauge
Rain (inches)
0
5
10
15
20
25
30
35
40
45
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Monthly Total
6 Month Decay

Ocala Rain Gauge

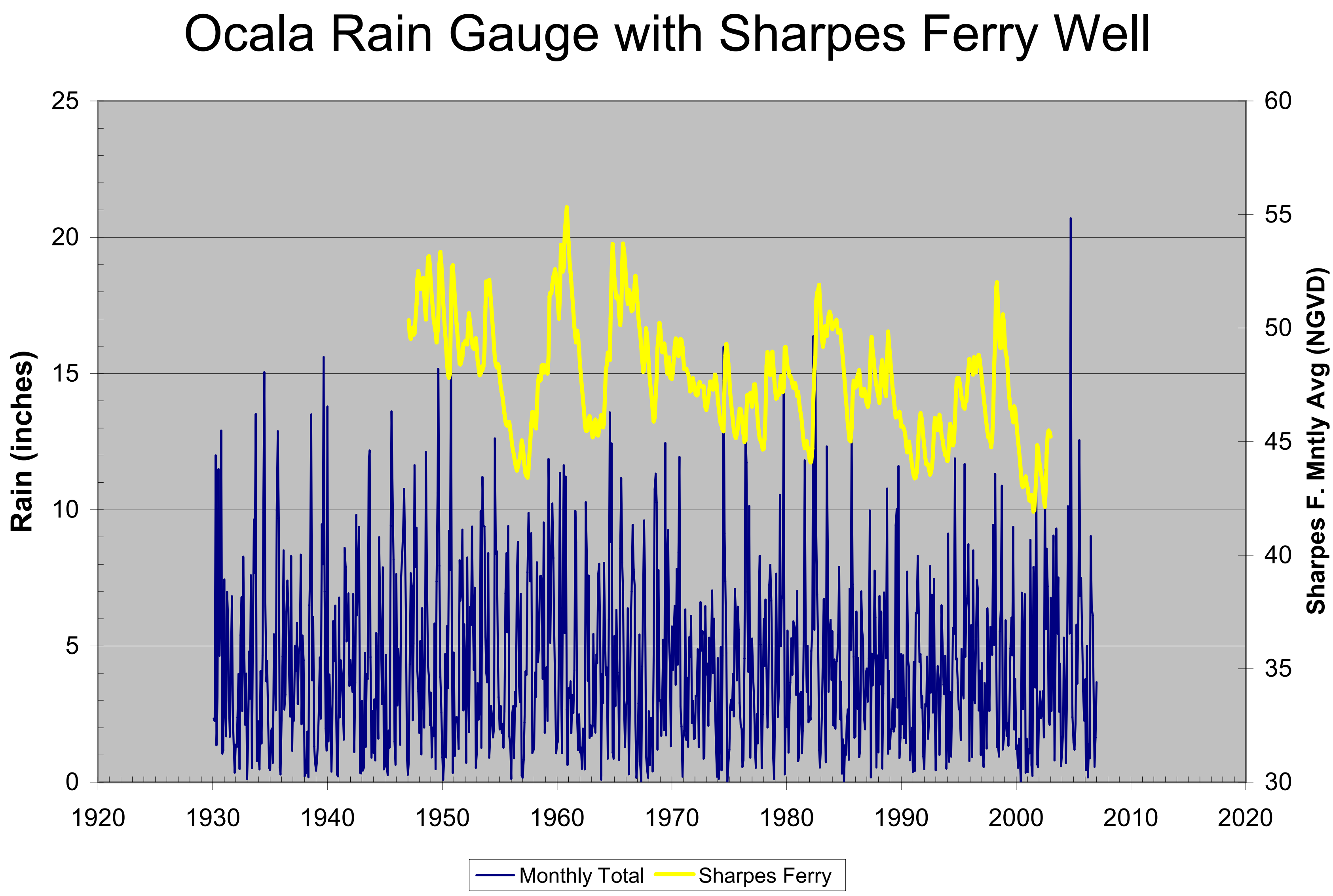


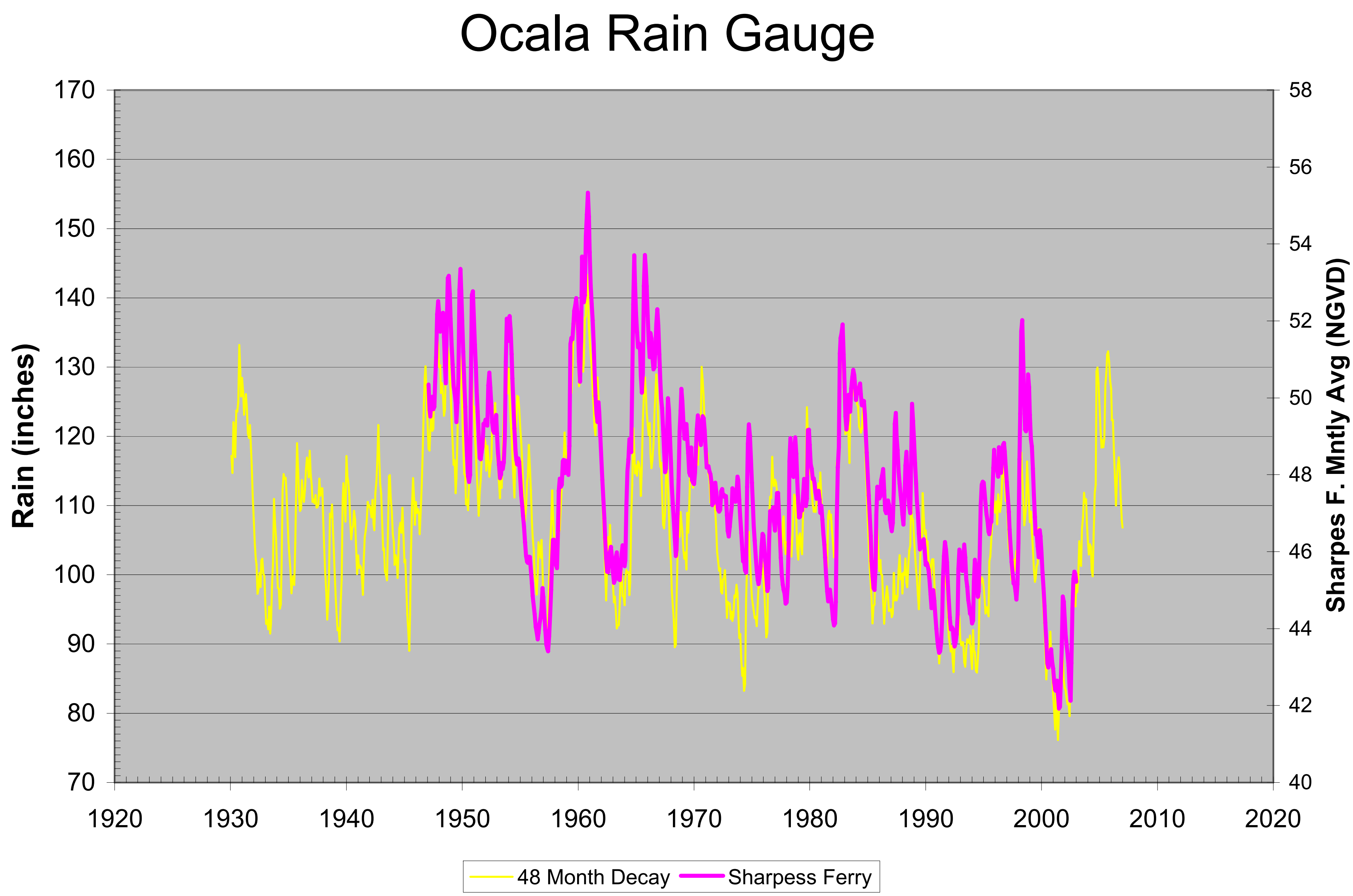
Ocala Rain Gauge





Ocala Rain Gauge
Rain (inches)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
48 Month Decay
72 Month Decay
60 Month Decay


Ocala Rain Gauge with Sharpes Ferry Well
Rain (inches)
Sharpes F. Mntly Avg (NGVD)
0
5
10
15
20
25
30
35
40
45
50
55
60
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Monthly Total
Sharpes Ferry



Ocala Rain Gauge
Rain (inches)
170
160
150
140
130
120
110
100
90
80
70
Sharpes F. Mntly Avg (NGVD)
58
56
54
52
50
48
46
44
42
40
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
48 Month Decay
Sharpess Ferry

Lake Models Based on Rainfall

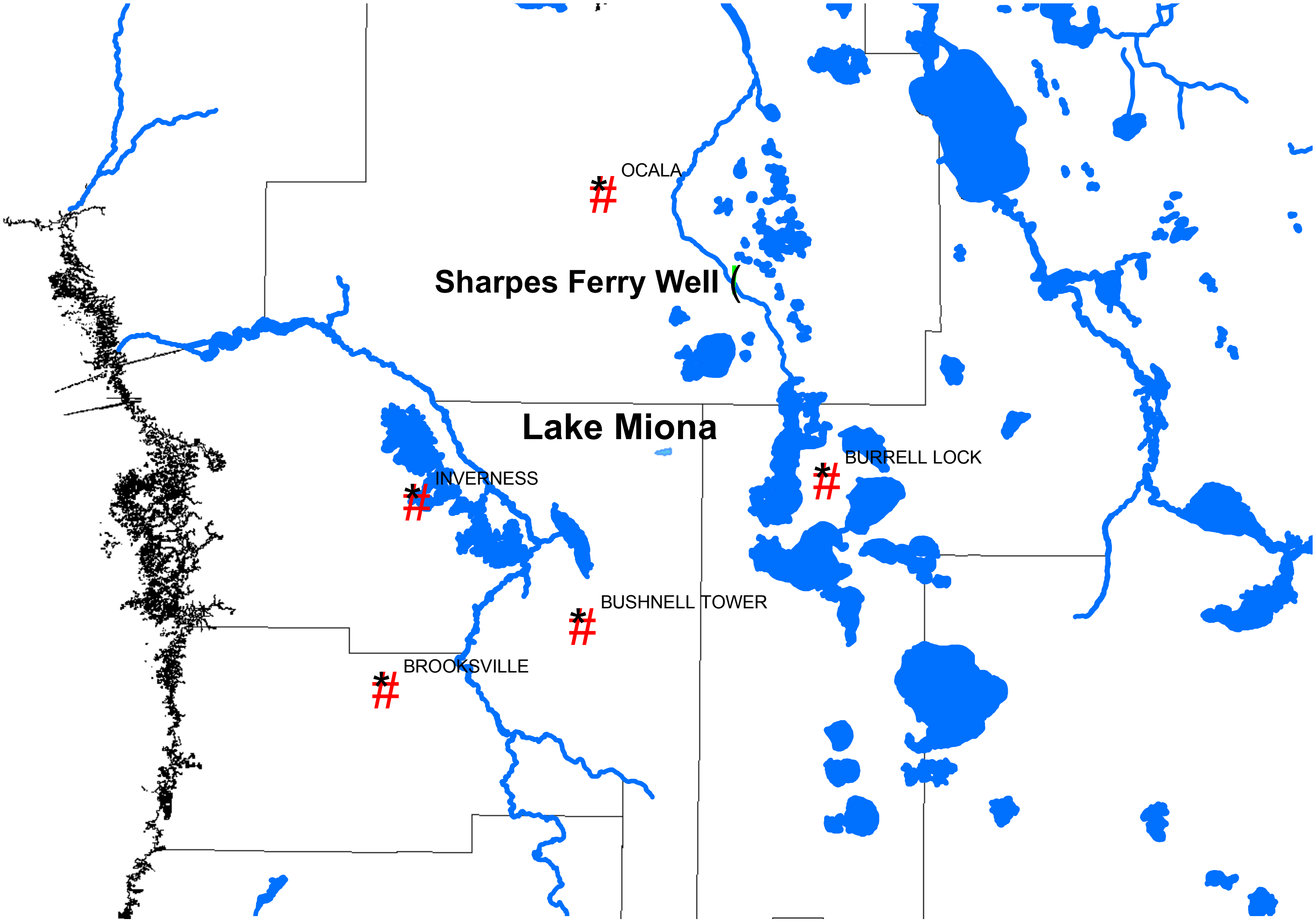
- The new decay series monthly totals are substituted for Sharpes Ferry water levels and the LOC model is ran in the same manner, with the following additional steps

Additional Steps

- Test Different Time Lengths for the Decay Series (12 month, 24 month, 36 month D…..)
- Compare each model and make selection using:
  - Lowest Absolute Sum of Percentile Differences
  - Highest r^2

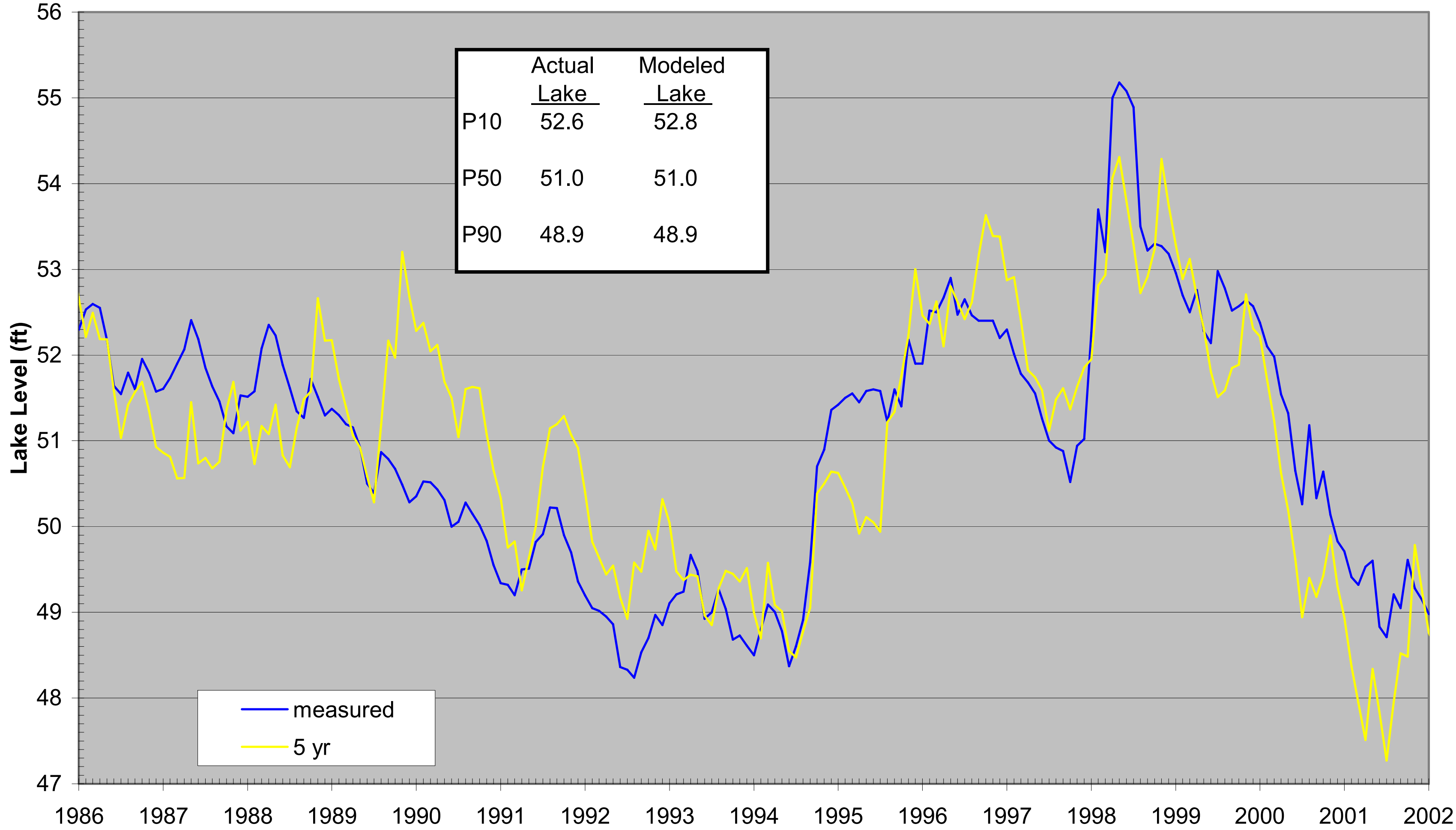
Additional Steps

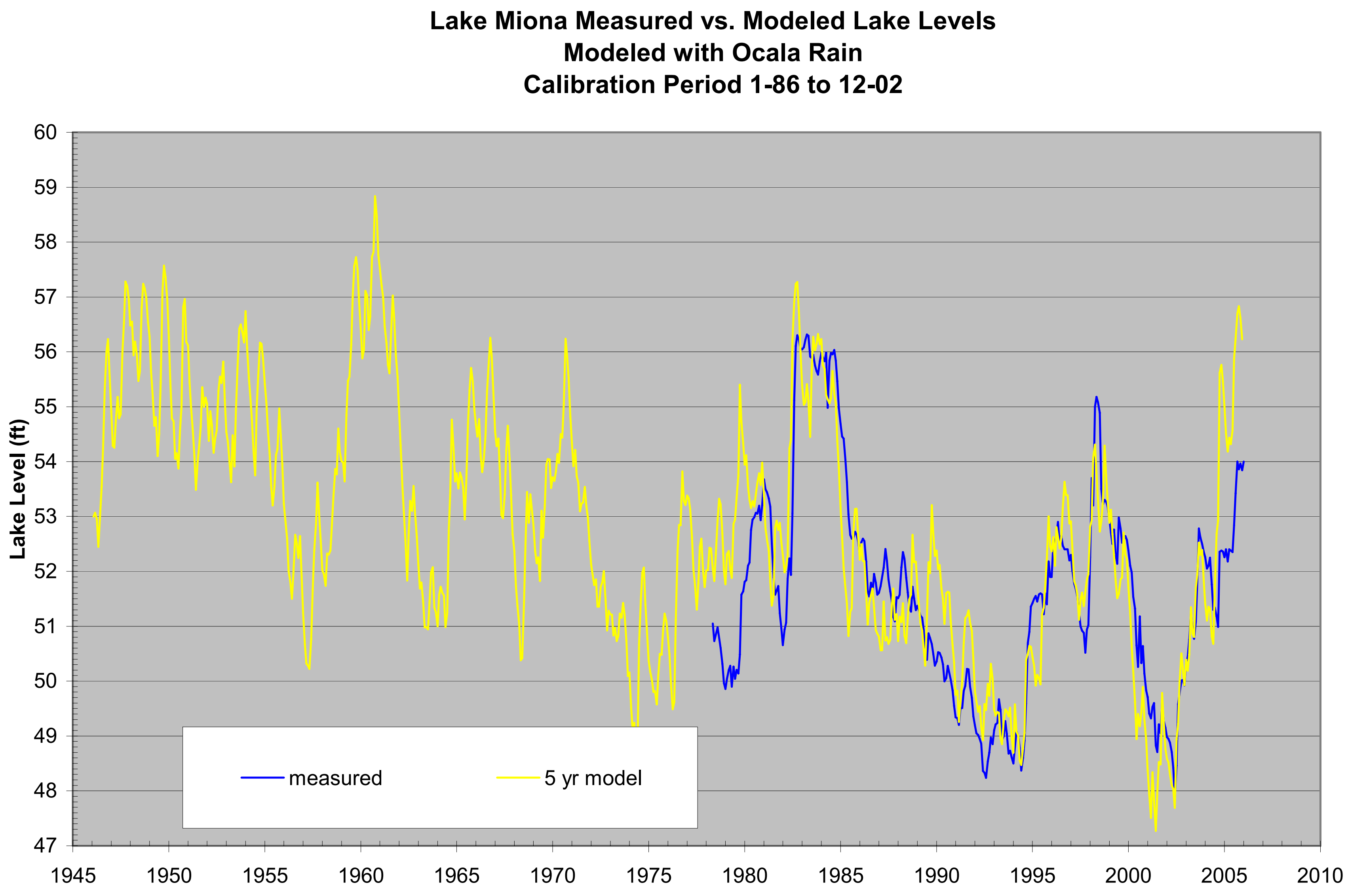
- Repeat for other nearby rain gauges approximately equal distance away from the lake
- Use same decision process on selection of best rain gauge and decay series time length
  - Lowest Absolute Sum of Percentile Differences
  - Highest r^2


OCALA
Sharpes Ferry Well
Lake Miona
INVERNESS
BURRELL LOCK
BUSHNELL TOWER
BROOKSVILLE

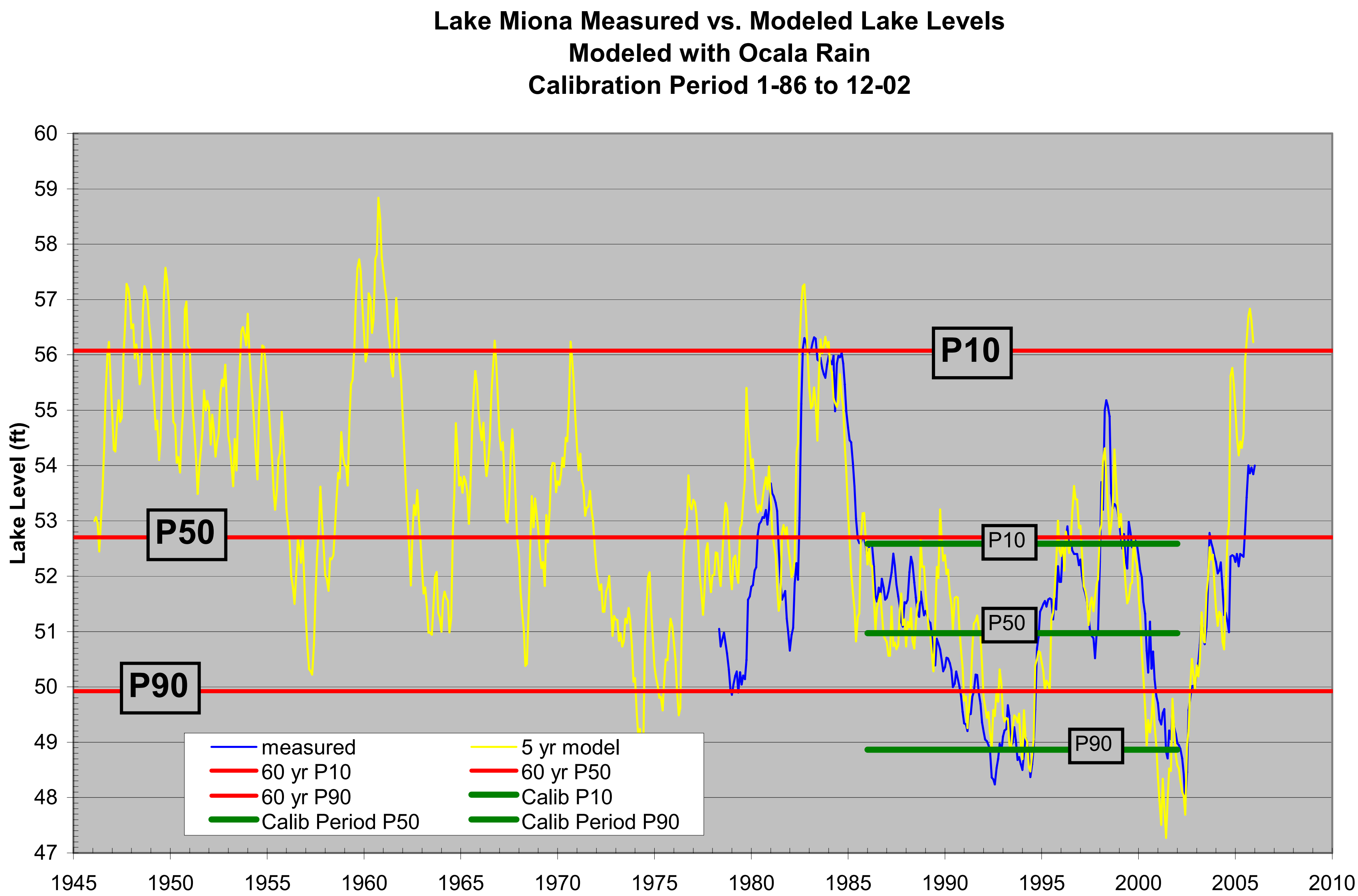
Decay Period	R^2	ppt Lake Model minus Measured/Lake Level Model Calib Per P50	ppt Lake Model minus Measured/Lake Level Model Calib Per P10	ppt Lake Model minus Measured/Lake Level Model Calib Per P90	ABS P50	ABS P10	ABS P90	Sum ABS
6 months	0.06	-0.22	0.45	0.12	0.22	0.45	0.12	0.80
1 year	0.21	-0.22	0.22	0.07	0.22	0.22	0.07	0.51
2 years	0.39	-0.12	0.24	0.11	0.12	0.24	0.11	0.48
3 years	0.52	-0.01	0.41	-0.01	0.01	0.41	0.01	0.43
4 years	0.61	-0.03	0.33	0.02	0.03	0.33	0.02	0.37
5 years	0.68	0.01	0.22	0.01	0.01	0.22	0.01	**0.24**
6 years	0.73	0.16	0.11	-0.09	0.16	0.11	0.09	0.36
7 years	0.74	0.13	0.08	-0.12	0.13	0.08	0.12	0.34
8 years	0.69	-0.05	0.18	-0.02	0.05	0.18	0.02	0.25
9 years	0.61	-0.10	0.12	-0.04	0.10	0.12	0.04	0.25
10 years	0.52	-0.09	0.21	0.03	0.09	0.21	0.03	0.33
Minimum	0.06							0.235
Maximum	0.74							0.799

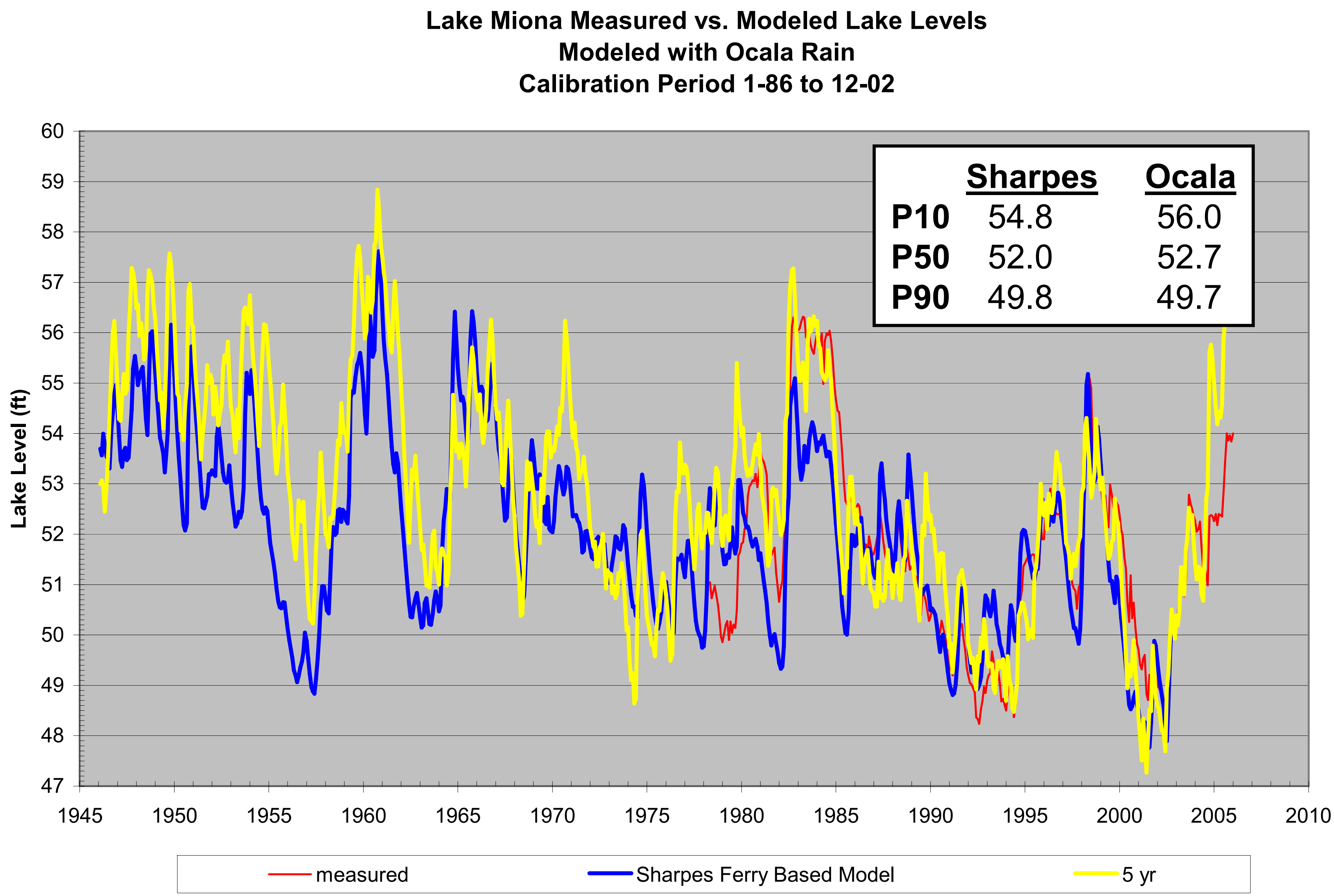
Lake Miona Measured vs. Modeled Lake Levels
Modeled with Ocala Rain
Calibration Period 1-86 to 12-02





Lake Miona Measured vs. Modeled Lake Levels
Modeled with Ocala Rain
Calibration Period 1-86 to 12-02
Lake Level (ft)
60
59
58
57
56
55
54
53
52
51
50
49
48
47
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
measured
5 yr model


Lake Miona Measured vs. Modeled Lake Levels
Modeled with Ocala Rain
Calibration Period 1-86 to 12-02
Lake Level (ft)
60
59
58
57
56
55
54
53
52
51
50
49
48
47
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
P10
P50
P90
P10
P50
P90
measured
5 yr model
60 yr P10
60 yr P50
60 yr P90
Calib P10
Calib Period P50
Calib Period P90



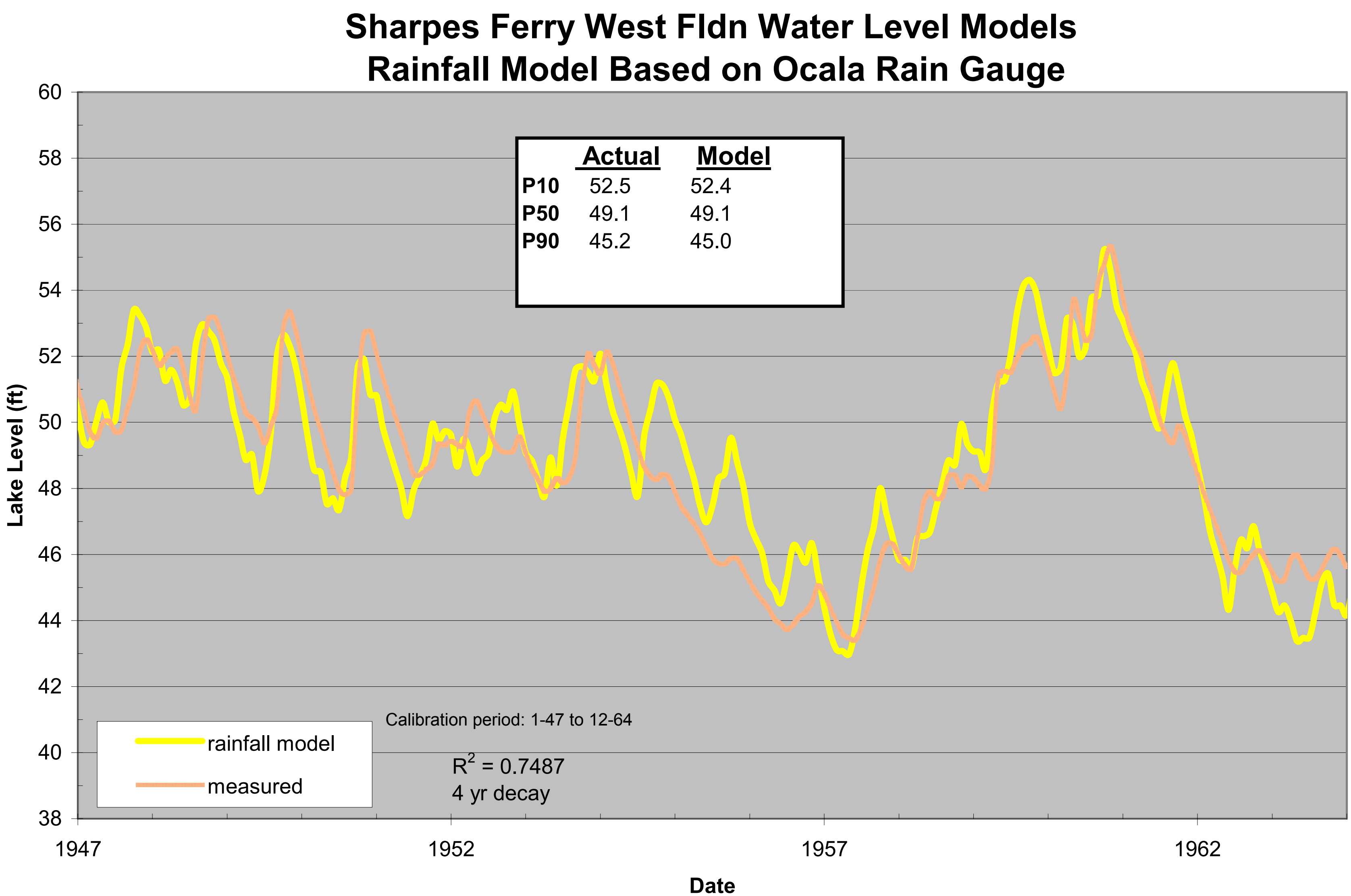
Lake Miona Measured vs. Modeled Lake Levels
Modeled with Ocala Rain
Calibration Period 1-86 to 12-02
Sharpes
Ocala
P10 54.8 56.0
P50 52.0 52.7
P90 49.8 49.7
Lake Level (ft)
60
59
58
57
56
55
54
53
52
51
50
49
48
47
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
measured
Sharpes Ferry Based Model
5 yr

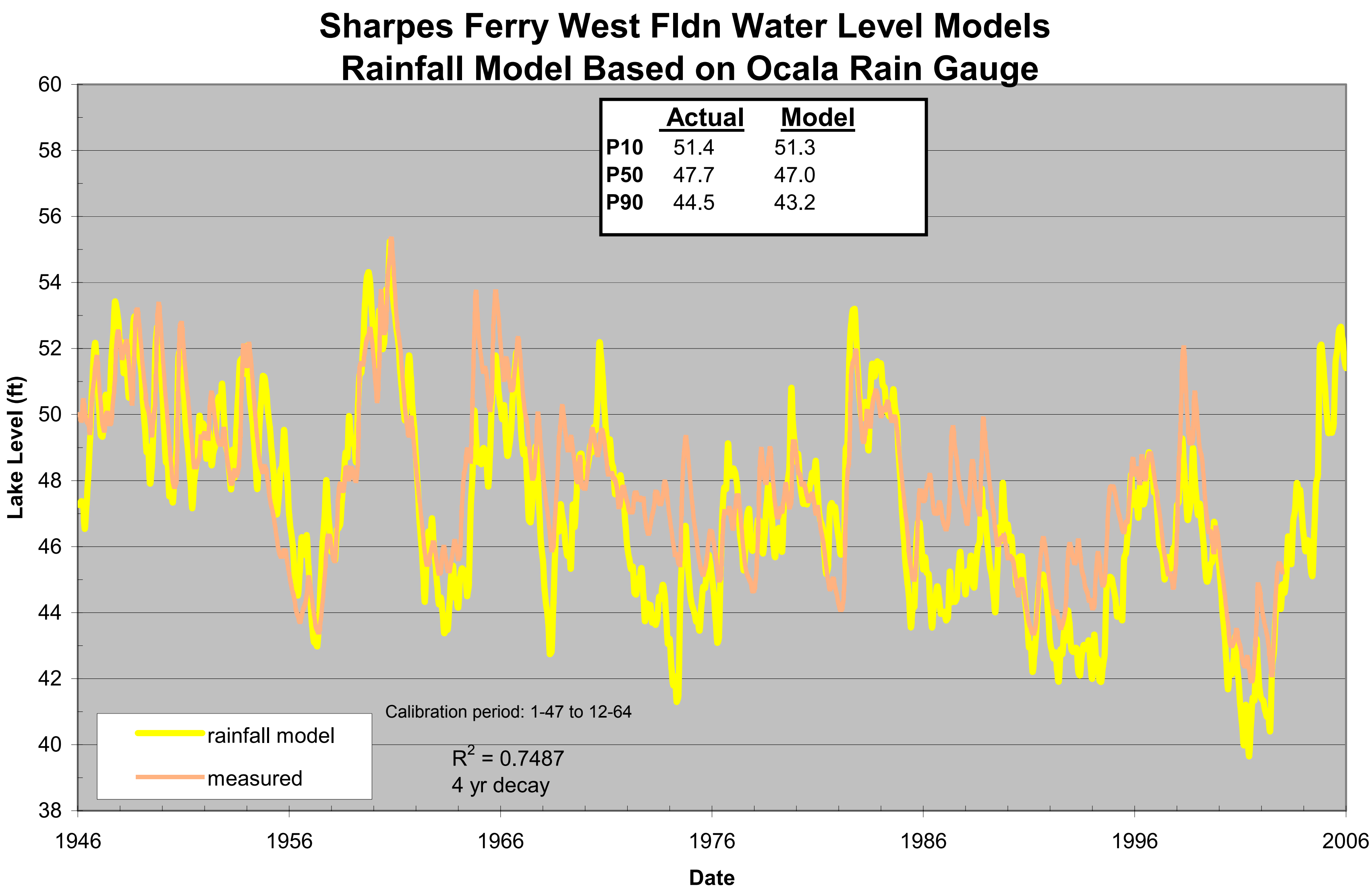
Rainfall Model 60 yr Test

- Model Sharpes Ferry Using Ocala Rainfall
- Use a Portion of Sharpes Ferry Well Data for Calibration
- Run Model and Project Out the Full 60 Years of Available Data
- Keep in Mind Some Changes to Ocklawaha River thus Possibly Some Changes to Sharpes Ferry

Model of Sharpes Ferry Well Using Ocala Rain
Calibration Period 1947 - 1964

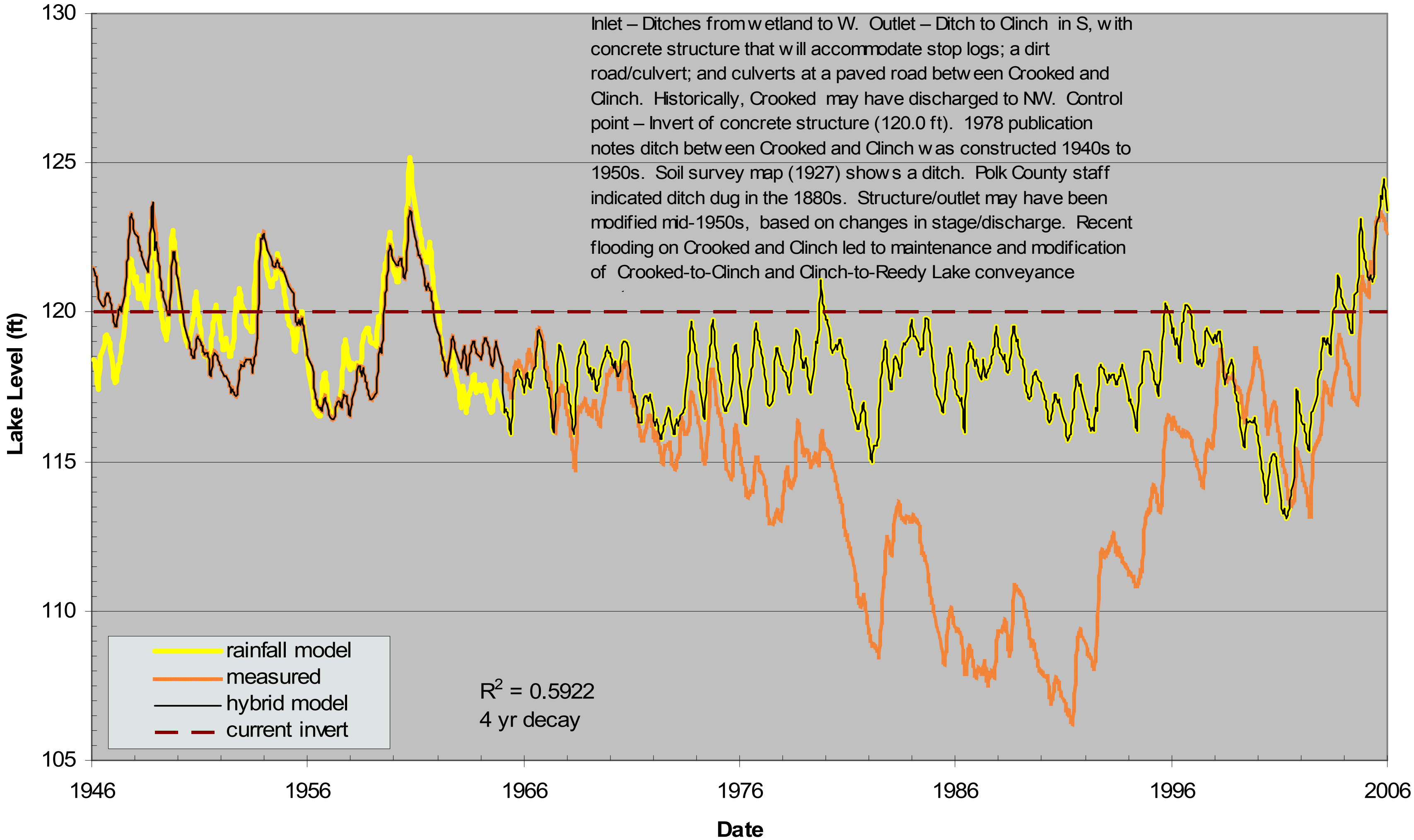
Decay Period	R^2	ppt Lake Model minus Measured/Lake Level Model Calib Per P50	ppt Lake Model minus Measured/Lake Level Model Calib Per P10	ppt Lake Model minus Measured/Lake Level Model Calib Per P90	ABS P50	ABS P10	ABS P90	Sum ABS
6 months	0.10	-0.20	0.17	0.19	0.20	0.17	0.19	0.56
1 year	0.34	-0.33	0.36	0.25	0.33	0.36	0.25	0.94
2 years	0.59	-0.14	0.00	-0.23	0.14	0.00	0.23	0.37
3 years	0.72	0.01	-0.19	-0.32	0.01	0.19	0.32	0.52
4 years	0.75	0.00	-0.10	-0.22	0.00	0.10	0.22	**0.32**
5 years	0.73	0.03	0.07	-0.33	0.03	0.07	0.33	0.43
6 years	0.70	0.07	-0.03	-0.35	0.07	0.03	0.35	0.45
7 years	0.68	0.36	-0.06	-0.20	0.36	0.06	0.20	0.62
8 years	0.66	0.31	-0.10	-0.22	0.31	0.10	0.22	0.64
9 years	0.61	0.31	-0.05	-0.26	0.31	0.05	0.26	0.61
10 years	0.55	0.26	-0.01	-0.27	0.26	0.01	0.27	0.53
Minimum	0.10							0.32
Maximum	0.75							0.94


Sharpes Ferry West Fldn Water Level Models
Rainfall Model Based on Ocala Rain Gauge
Actual
Model
P10
52.5
52.4
P50
49.1
49.1
P90
45.2
45.0
Lake Level (ft)
60
58
56
54
52
50
48
46
44
42
40
38
1947
1952
1957
1962
Date
rainfall model
measured
Calibration period: 1-47 to 12-64
R2 = 0.7487
4 yr decay



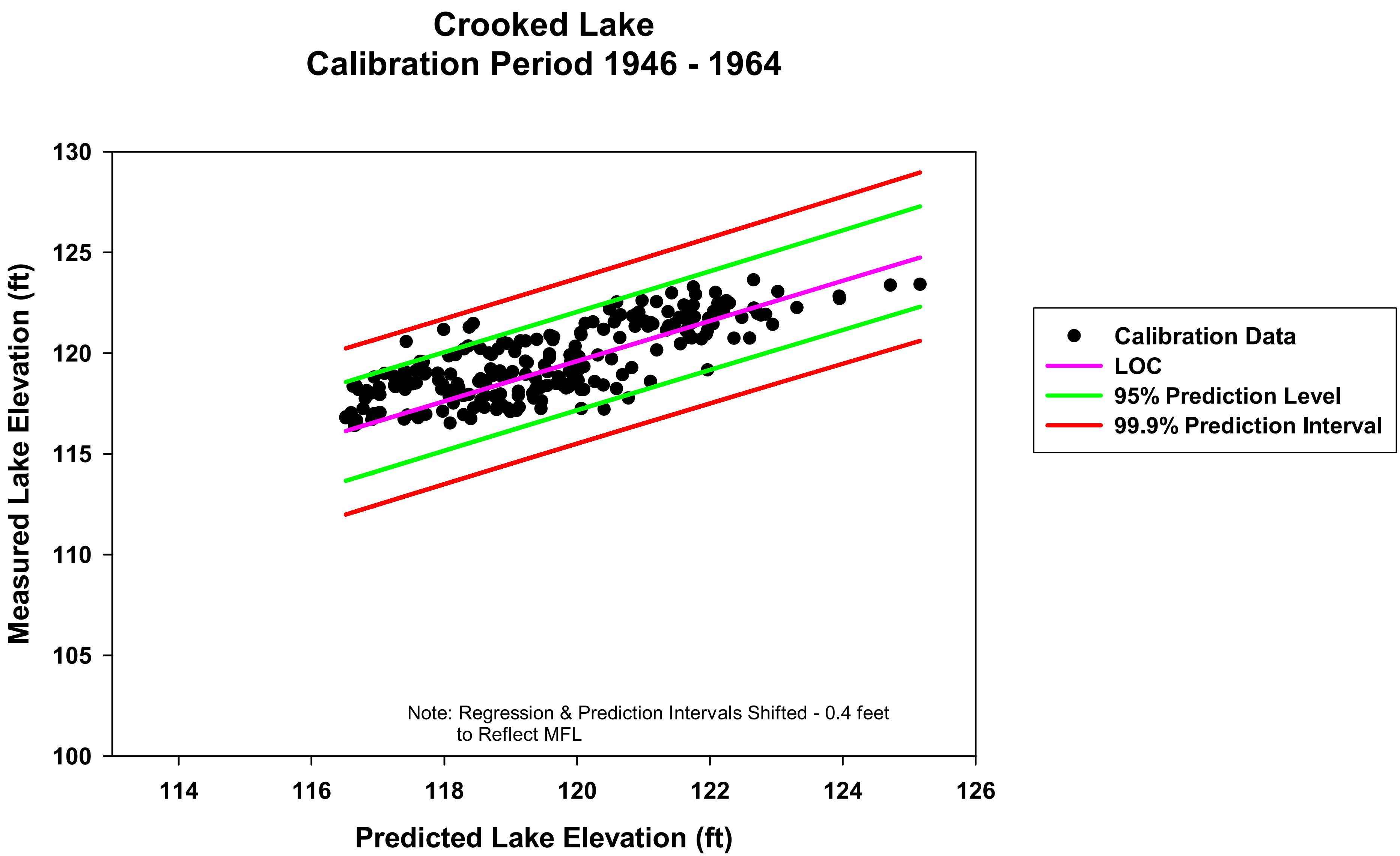
Sharpes Ferry West Fldn Water Level Models
Rainfall Model Based on Ocala Rain Gauge
Actual
Model
P10 51.4 51.3
P50 47.7 47.0
P90 44.5 43.2
Lake Level (ft)
60
58
56
54
52
50
48
46
44
42
40
38
1946
1956
1966
1976
1986
1996
2006
Date
rainfall model
measured
Calibration period: 1-47 to 12-64
R² = 0.7487
4 yr decay

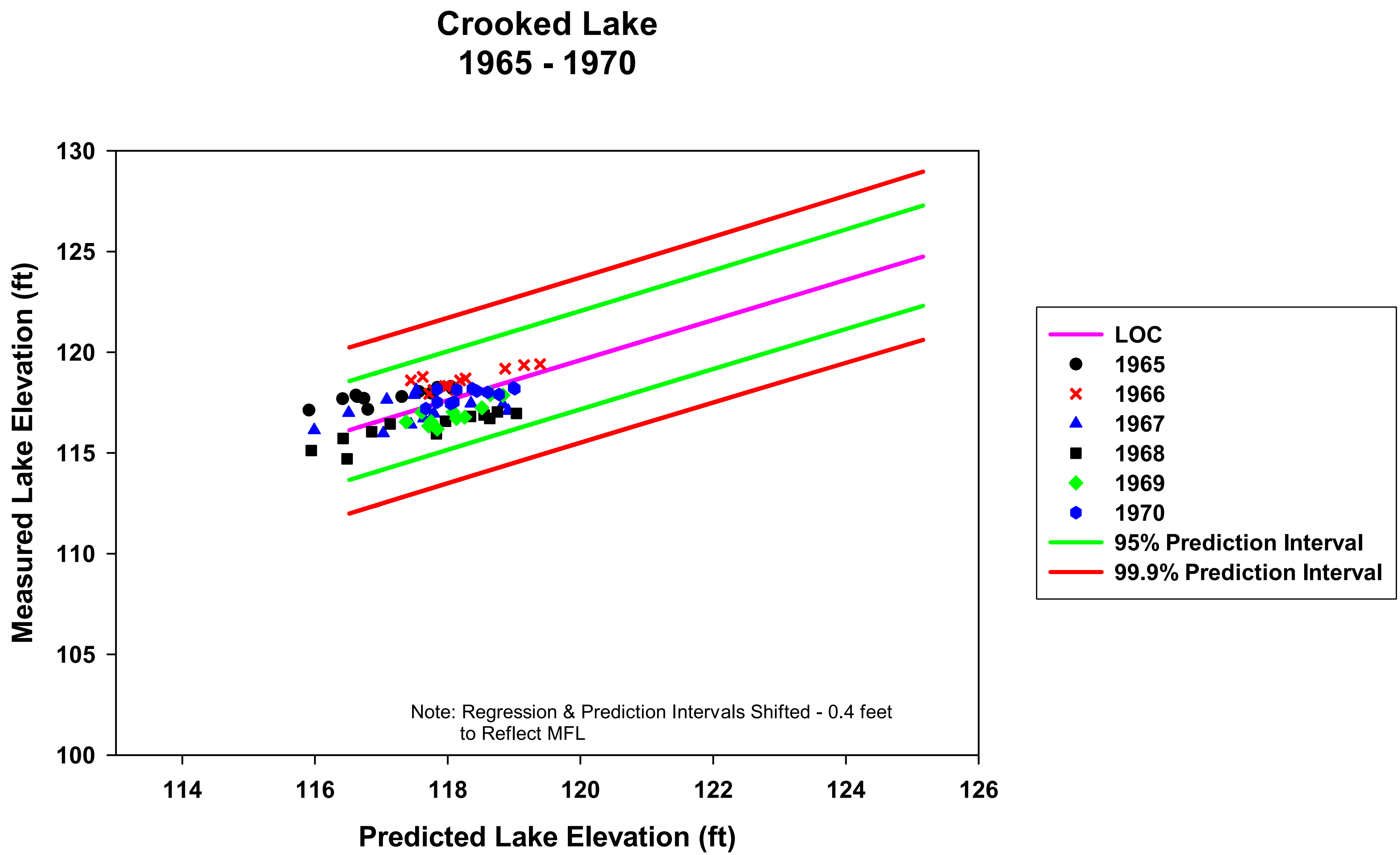
Crooked Water Level Models
Rainfall Model Based on Mountain Lake Rain Gage

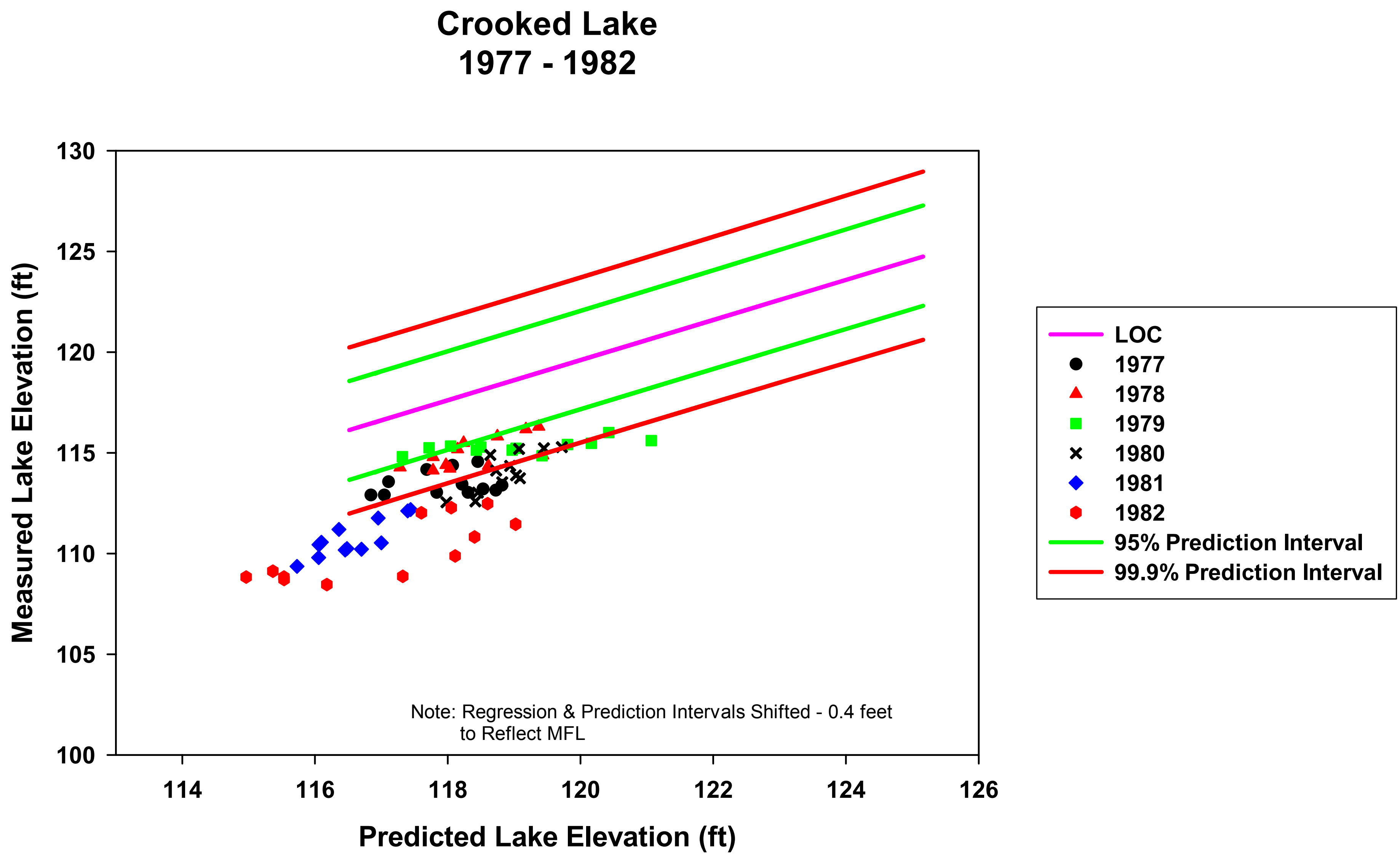


Future Discussion

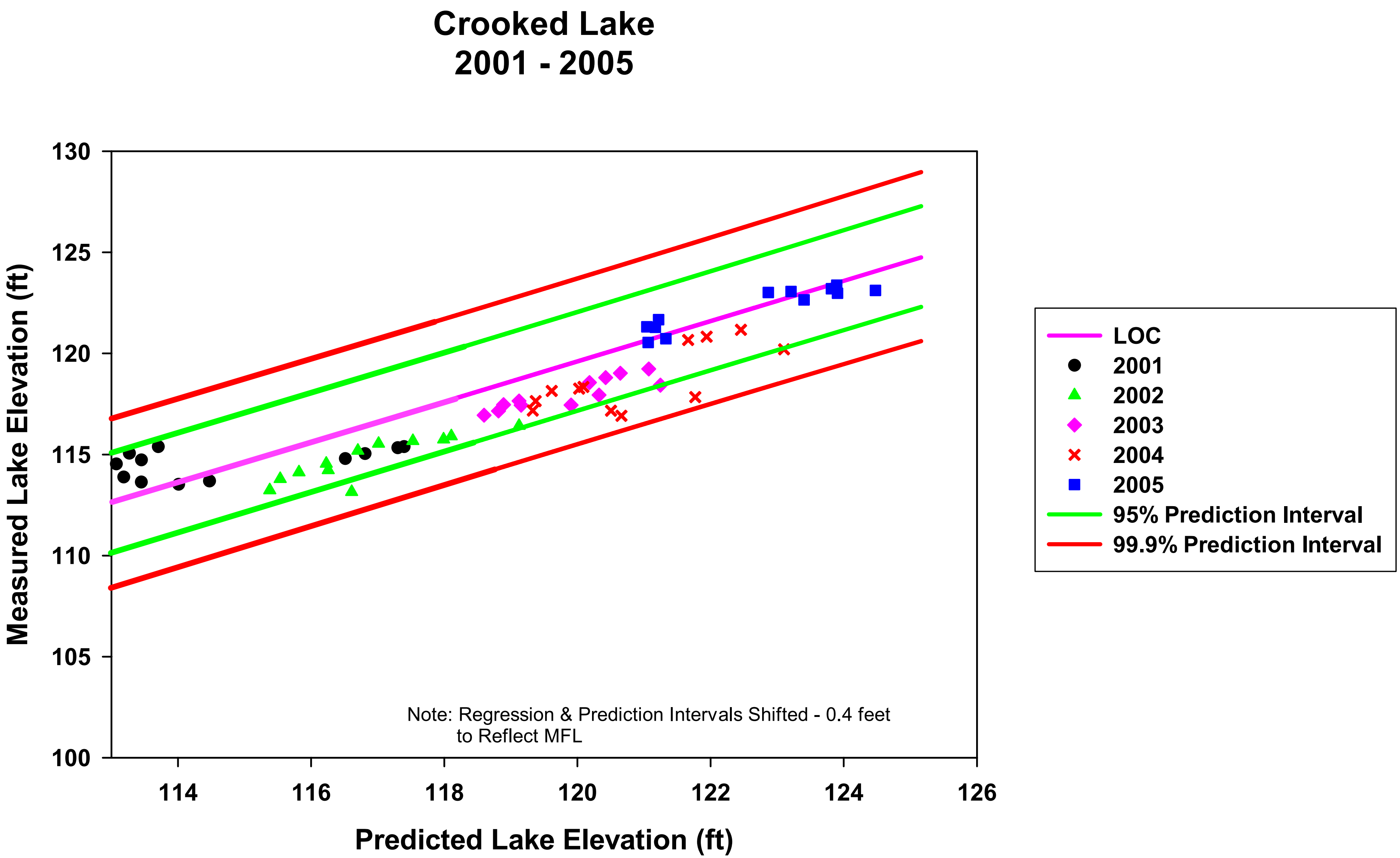
Evaluation of Compliance Based on Climatic Conditions


Crooked Lake
Calibration Period 1946 - 1964
130
125
120
115
110
105
100
114
116
118
120
122
124
126
Measured Lake Elevation (ft)
Predicted Lake Elevation (ft)
Note: Regression & Prediction Intervals Shifted - 0.4 feet
to Reflect MFL
Calibration Data
LOC
95% Prediction Level
99.9% Prediction Interval


Crooked Lake
1965 - 1970
Measured Lake Elevation (ft)
Predicted Lake Elevation (ft)
130
125
120
115
110
105
100
114
116
118
120
122
124
126
LOC
1965
1966
1967
1968
1969
1970
95% Prediction Interval
99.9% Prediction Interval
Note: Regression & Prediction Intervals Shifted - 0.4 feet
to Reflect MFL



Crooked Lake
1977 - 1982
Measured Lake Elevation (ft)
Predicted Lake Elevation (ft)
130
125
120
115
110
105
100
114
116
118
120
122
124
126
LOC
1977
1978
1979
1980
1981
1982
95% Prediction Interval
99.9% Prediction Interval
Note: Regression & Prediction Intervals Shifted - 0.4 feet
to Reflect MFL


Crooked Lake
2001 - 2005
Measured Lake Elevation (ft)
Predicted Lake Elevation (ft)
130
125
120
115
110
105
100
114
116
118
120
122
124
126
Note: Regression & Prediction Intervals Shifted - 0.4 feet
to Reflect MFL
LOC
2001
2002
2003
2004
2005
95% Prediction Interval
99.9% Prediction Interval